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CERTIFICATION PAGE

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In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

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The undersigned certifies, to the best of his or her knowledge and belief, that:

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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
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Collaborative Proposal for Development of Nuclear Targets and Calibration Systems for the MINERνA Neutrino Experiment

Hampton University[§], University of Minnesota-Duluth[†], University of Pittsburgh[†,§], University of Rochester[†,§], College of William and Mary[†]

[§] Experimental Nuclear Physics [†] Experimental Particle Physics

Intellectual Merit: The NUMI beamline delivered its first neutrinos to the MINOS experiment in early 2005, and will provide the highest intensity neutrino beam in the world for many years to come. This new beam offers the particle and nuclear physics communities a new opportunity. The MINERνA experiment proposes to exploit this opportunity to initiate a broad and rich program in neutrino scattering physics by constructing a fully active neutrino detector to run for the first time in a high rate neutrino beam.

The MINERνA physics program consists of high rate studies of exclusive final states in neutrino scattering, of the transition between the perturbative and the non-perturbative QCD regime, and of the axial current in the elastic, DIS and off-forward regimes. In addition, MINERνA proposes to carry out this program on various nuclei to systematically probe neutrino-induced nuclear effects. MINERνA can address these topics with a low-risk detector of modest cost. The performance of this detector will be excellent for resolving exclusive processes and for measuring kinematics in inclusive reactions.

In addition to the inherent interest of these topics, the MINERνA measurements will be vital to present and future neutrino oscillation experiments that represent one of the most important (and expensive) frontiers of particle physics. Measurements such as MINERνA's were recently stressed in the APS Multidivisional Neutrino Study report. This report predicated its recommendations on a set of "assumptions" about the current and future program, including

> *"determination of the neutrino reaction and production cross sections required for a precise understanding of neutrino-oscillation physics and the neutrino astronomy of astrophysical and cosmological sources. Our broad and exacting program of neutrino physics is built upon precise knowledge of how neutrinos interact with matter."*

Broader Impact: The MINERνA collaboration currently consists of 73 nuclear and particle physicists from 17 universities in five countries and two US national laboratories (Fermilab and Jefferson Lab). The subset of University groups represented in this proposal have strong records of training graduate and undergraduate students and post-doctoral physicists in experiments of the Fermilab neutrino program and at Jefferson Lab. To build on these records, we propose a program of education and public outreach activities associated with the construction and physics of MINERνA.

MINERνA, Fermilab and this Proposal: MINERνA received Stage I approval from the Fermilab PAC in April 2004. In FY05-06, Fermilab funded significant R&D and design activities associated with MINERνA, both at the lab and at collaborating Universities. As detailed in the accompanying Letter of Support, Fermilab plans to complete the construction of the base MINERνA detector with FY07-08 construction funds. Fermilab is committed to run the NuMI beamline through at least 2009, and other proposals that use the beamline in the more distant future have been approved by Fermilab. We therefore anticipate a long-term physics program, perhaps spanning up to a decade.

This proposal requests support for the collaborating university groups to construct nuclear targets and critical calibration systems for MINERνA. Funding this proposal will result in significant improvements in the MINERνA detector capabilities, both by extending the range of nuclei over which nuclear interactions can be studied, and by improving the ability of the experiment to reconstruct exclusive final states through an aggressive program of calibration culminating in a testbeam run. The funds requested in this proposal will allow the University collaborators to purchase materials and equipment and employ the technical staffs necessary to construct nuclear targets, a module mapper, a light injection system and a testbeam detector. Fermilab will supplement these funds with labor support for the construction of the testbeam detector and nuclear targets, infrastructure for the cryogenic target, and operation of an instrumented testbeam for the proposed MINERνA testbeam detector.

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*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

1 Research Activities: The MINERνA Physics Program

MINERνA [1] offers a unique opportunity to explore a broad spectrum of physics topics; some have never been studied systematically, while others are plagued by sparse data with large statistical and systematic errors. The high-statistics studies listed below are important for both the particle and nuclear physics communities, and provide information complementary to Jefferson Lab (JLab) charged lepton studies in the same kinematic range.

- Precision measurement of the quasi-elastic neutrino–nucleus cross-section, including its E_ν and Q^2 dependence, and study of the nucleon axial form factors. Over **300 K** events are expected in the fiducial volume during a four-year MINERνA run.
- Determination of cross-sections in the resonance-dominated region for both neutral-current (NC) and charged-current (CC) interactions. A total of **470 K** one- and two-pion events make up the resonance sample.
- Precision measurement of coherent single-pion production cross-sections, with particular attention to target A-dependence. NC coherent pion production is a significant background for next-generation neutrino oscillation experiments probing $\nu_\mu \rightarrow \nu_e$ oscillation. A sample of **20 K** CC events is expected off carbon. The expected NC sample is roughly half the CC sample.
- Examination of nuclear effects in neutrino interactions, including final-state modifications in heavy nuclei, by employing carbon, iron and lead targets. These effects play a significant role in neutrino oscillation experiments measuring ν_μ disappearance as a function of E_ν. With sufficient $\overline{\nu}$ running, a study of flavor-dependent nuclear effects can also be performed. Due to the different mix of quark flavors, this is another way in which neutrino and charged-lepton nuclear effects differ. MINERνA will collect over **700 K** CC events off both iron and lead, in addition to the carbon sample.
- Exploration of the W (hadronic mass) transition region where resonance production merges with deep-inelastic scattering (DIS), testing phenomenological models like quark/hadron duality. A sample of **500 K** multi-pion events is expected with W $\leq$ 2.0 GeV.
- With a sample of over **1 M** CC DIS events, a much-improved measurement of the parton distribution functions, particularly at large x_{Bj}, will be possible using a measurement of all three ν structure functions. Although we expect over **100 K** CC $\overline{\nu}$ events in the four year MINERνA ν run, an additional dedicated $\overline{\nu}$ run would be required to measure the three $\overline{\nu}$ structure functions with similar precision.
- With nearly **50 K** fully reconstructed exclusive events[2], precision measurement of exclusive strange-production channels near threshold. This will significantly improve our knowledge of backgrounds in nucleon-decay searches.
- Improved determination of the effective charm-quark mass (m_c) near threshold, and new measurements of V_{cd}, $s(x)$ and, independently, $\overline{s}(x)$.

These are worthy research topics on their own, and improved knowledge in most is essential to minimizing systematic uncertainties in neutrino-oscillation experiments. The remainder of this section provides more detail, and illustrates the rich physics potential of MINERνA.

1.1 Low-energy Neutrino Cross-sections: Quasi-elastic Scattering

CC quasi-elastic reactions play a crucial role in non-accelerator and accelerator-based neutrino oscillation studies. Cross-section uncertainties - often expressed as uncertainty in the axial-vector mass - are a significant contribution to the errors of these experiments. Available measurements of this cross-section are clustered below E_ν = 5 GeV with a few isolated measurements out to 12 GeV. The measurements have statistical errors of 10–15%, plus systematic flux errors of 10–20%. A full simulated analysis of the quasi-elastic channel in MINERνA has been carried out [3]. The efficiency and purity of the final sample are Q^2 dependent, but the average efficiency was 74% with a purity of 77%. The expected results are shown in Figure 1. MINERνA will measure the cross-section up to E_ν = 20 GeV with statistical errors ranging from $\leq$ 1% at low E_ν up to 7 % at E_ν = 20 GeV. The expected beam systematic error is 4–6% thanks to precision measurements of hadron production (the largest uncertainty in predicting neutrino flux) by the current MIPP experiment [4].

Figure 1 shows the extraction of the axial-vector form factor from the quasi-elastic event sample accumulated over a 4-year MINERνA run. Since MINERνA can measure the axial nucleon form-factor with

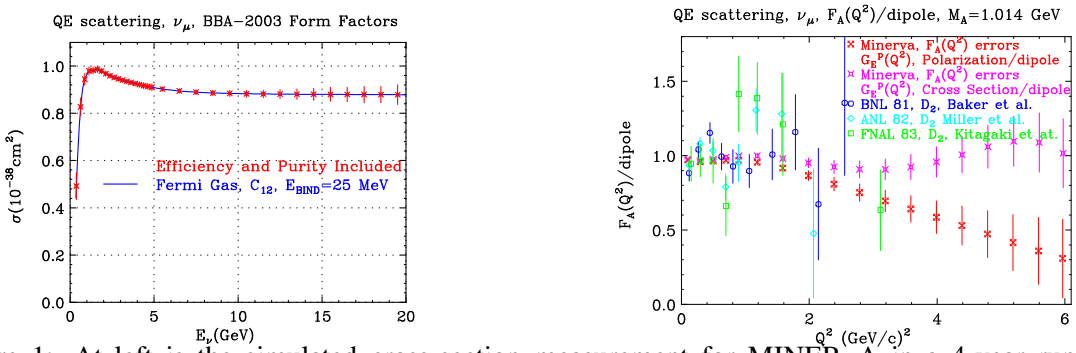

Figure 1: At left is the simulated cross-section measurement for MINERνA in a 4-year run (statistical errors only) assuming M_A=1.00 GeV and the Fermi gas model. At right are the projected axial form-factor results for MINERνA for two different assumptions: F_A/dipole=G_E^p/dipole from cross-section and F_A/dipole=G_E^p/dipole from polarization. Also shown are the extracted values of $F_A(q^2)$/dipole for deuterium bubble chamber experiments Baker *et al.* [5], Kitagaki *et al.* [6] and Miller *et al.* [7].

precision comparable to vector form-factor measurements at JLab, combining them with present and future Jefferson Lab data will permit precision extraction of all form factors needed to improve and test models of the nucleon.

1.2 Low-energy Neutrino Cross-sections: Resonance Production

The theoretical and experimental picture of the resonance and transition regions is far more obscure than the quasi-elastic and DIS regions which border it. To simulate resonance-mediated reactions, Monte-Carlo programs use early theoretical predictions by Rein & Sehgal [8] or results from electro-production experiments, since existing data on neutrino-induced resonance production is inadequate. Since the event samples of present and proposed neutrino oscillation experiments fall inside this poorly-understood regime, resonant pion production is an important source of background and systematic uncertainty. This kinematic region will be carefully examined by MINERνA, over a broad range in target nuclei.

Analysis of resonance production in MINERνA[9] will focus on several experimental channels, including inclusive scattering in the resonance region ($W < 2$ GeV) and exclusive charged and neutral pion production. To date, analysis efforts have focused on MINERνA's performance for inclusive resonance production [10], particularly near the $\Delta(1232)$ resonance. This analysis with even our preliminary tracking capabilities indicates that the resolution on W is about 100 MeV in the region of the Δ, and the Q^2 resolution is better than 20%. Despite this resolution smearing, and distortion introduced by Fermi motion of bound nucleons in carbon, the Δ peak is still clearly visible in the reconstructed W distribution.

1.3 Low-energy Neutrino Cross-sections: Coherent Pion Production

Both CC and NC coherent scattering result in a single forward-going pion with little energy transfer to the target nucleus. For neutral-currents, the forward-going π^0 can mimic an electron and be misinterpreted as a signal in ν_e appearance experiments. Existing cross-section measurements for this reaction are only accurate to 35%, at best, and only available for a limited number of target nuclei at few to ten GeV in energy [11].

MINERνA, with its high statistics and variety of nuclear targets, will greatly improve our experimental understanding of coherent processes. A complete simulated analysis of the CC coherent production channel has been carried out [12]. The kinematic cuts employed reduce the background by three orders of magnitude while reducing the signal by only a factor of three.

Figure 2 shows the estimated statistical precision of MINERνA's CC coherent scattering measurement, as a function of neutrino energy, after background subtraction. The model of Rein & Seghal [13] is assumed. Also plotted are the only currently available measurements in this kinematic region showing their total errors.

MINERνA will also compare the reaction rates for lead, iron and carbon. The A dependence of the cross-section depends mainly on the assumed model of the hadron–nucleus interaction and serves as a crucial test for that component of the predictions [14]. No experiment to date has been able to perform this comparison.

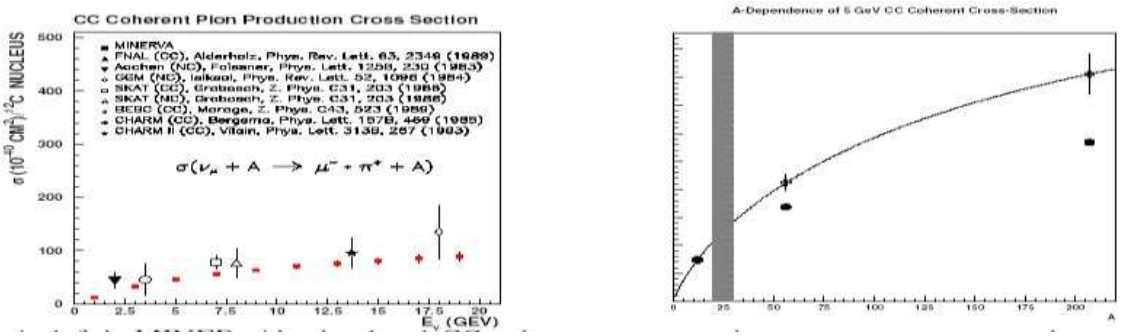

Figure 2: At left (right) is MINERνA's simulated CC coherent cross-section measurement versus neutrino energy (target nucleus), assuming a 4-year run, statistical errors only, compared with published data. At right, the data are compared to the narrow range of existing data, shown by the shaded band.

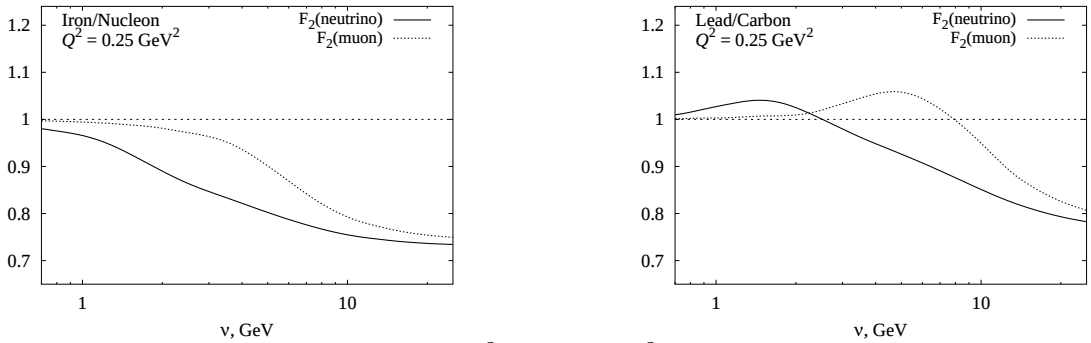

Figure 3: Predicted shadowing effects at $Q^2 = 0.25$ GeV^2 as a function of energy transfer (ν), for neutrinos (solid line) and muons (dotted line). The plot on the left is for iron compared to deuterium while the right plot is lead compared to carbon, what MINERνA will measure.

Figure 2 illustrates the broad range in A covered by MINERνA's measurement of the coherent pion cross-section. The shaded band is the range in A measured by previous experiments.

1.4 Nuclear Effects in Neutrino Scattering

Most neutrino scattering experiments, including neutrino oscillation experiments, require massive nuclear target/detectors to obtain useful reaction rates. Analysis of neutrino reactions with nuclear media requires understanding the nuclear environment's effect on the process [15]. There are two general categories of such nuclear effects:

- The neutrino interaction probability on nuclei is modified relative to free nucleons. Nuclear effects of this type have been extensively studied in DIS structure function measurements using muon and electron beams, but have not been explored with neutrinos. Depending on the kinematic region, these nuclear effects can be quite different for neutrinos, particularly the shadowing phenomenon [16]. Figure 3 shows the predicted difference between neutrino and charged lepton shadowing as a function of the energy transfer (ν). The projected statistical error on the ratio of lead to carbon is order 2% at ν = 6 GeV. Without MINERνA, there are no data available to measure this important effect .

- Hadrons produced in a nuclear target may undergo final-state interactions (FSI), including re-scattering and absorption. These effects may significantly alter the observed final-state configuration and measured energy [17, 18], and are sizable at neutrino energies typical of current and planned oscillation experiments [19].

The hadron shower observed in neutrino experiments is actually the *convolution* of these two effects.

To study these questions in MINERνA, the baseline detector design calls for carbon, iron and lead targets with fiducial masses between 500 and 1000 kg to be installed upstream of the pure scintillator active detector. To measure the overall effect [15] of the nucleus, the observed hadron energy and multiplicity will be measured for all three targets as a function of muon variables to determine an (A,p$_\mu$) correction factor to the visible hadron energy of CC events. In addition, this proposal will support construction of a cryogenic He target with a fiducial mass of approximately 100 kg.

1.4.1 Addition of a Cryogenic Helium Target

Understanding the nuclear dependence of inclusive structure functions is one of the principle goals of the MINERνA experiment, in particular in the nuclear shadowing regime where a range of dramatic effects are predicted for the axial current [20, 21]. Moreover, the ability to clearly ascertain the nuclear dependence of neutrino cross sections and structure functions from the MINERνA data will be crucial model input for the current and upcoming generation of neutrino oscillation experiments. While it is now possible to identify some of the ingredients necessary to explain the nuclear dependence of structure functions, other components are still unknown, and there exist competing models based on significantly different pictures of the origin of the nuclear dependence. An overview of measurements and models of the nuclear dependence of inclusive structure functions may be found in [22]. The proposed MINERνA helium (He) target will provide an unprecedented lever arm in atomic number, A.

In the valence regime in the quark model, the nuclear dependence of the structure functions (here, the EMC effect primarily) is expected to be the same for both the vector and axial currents, i.e. for electron and neutrino experiments. Yet, at what four-momentum Q^2 this holds true has not been tested, and the meson dominance contributions are expected to be different [21]. Knowing where the former is valid would be most beneficial to neutrino experiments, as it would provide a kinematic marker in Bjorken x and Q^2 for where parameterizations of the EMC effect from electron scattering (where the effect is well measured) are directly applicable. The He target data from MINERνA will facilitate this, as a comparison of heavy to light targets is required. Used in conjunction with the soon-to-be-available He and heavy target results from Jefferson Lab experiment E03-103 and previous SLAC measurements [24], it will be possible for the first time to determine, and to do so carefully with matched targets and kinematics, where the EMC effect is the same and different in electron and neutrino scattering.

The heavy to light (He) target ratios will also improve the proposed shadowing regime studies. Nuclear effects on the measured cross sections will be more conspicuous the larger the A difference in targets compared.

The He target will also provide improved precision to MINERνA's planned extractions of nucleon structure functions from nuclei. The four-body wavefunction of He is far better known than that for heavy nuclei. Reliable Quantum Monte Carlo calculations have been done for up to A=10 nuclei [25], but not beyond. This introduces a large uncertainty on extractions of nucleon information from even the MINERνA carbon data, which is at a relatively low A for neutrino experiments. The wave function for He, on the other hand, is relatively well understood and will allow for precise extractions of bound nucleon structure.

This last fact will also facilitate exploratory studies of the still mysterious origin of the EMC effect, constraining the density and off-shell dependencies of the effect. Rescattering effects can be corrected for since the microscopic calculations are available for He.

New measurements of the EMC effect will have implications on bound form factor measurements. Extracting the axial form factor is one of MINERνA's goals. There is currently much controversy surrounding the extraction of form factors in the nuclear medium, where the medium may cause internal modifications of nucleon structure. New form factor data from Jefferson Lab on He favor a predicted medium modification [26]. A He target is optimal for studying medium modifications since its relative simplicity allows for realistic microscopic calculations and its high density enhances possible medium effects.

1.5 The Perturbative - Non-Perturbative Interface and Deep-Inelastic Scattering

Three decades after the establishment of QCD as the theory of the strong interaction, understanding *how* QCD works remains one of the great challenges in elementary particle and nuclear physics. A major obstacle arises because the degrees of freedom observed in nature (hadrons and nuclei) are totally different from those appearing in the QCD Lagrangian (current quarks and gluons). Making the transition from quark and gluon to hadron degrees of freedom is therefore the key to our ability to describe nature from first principles.

Despite the apparent dichotomy between the partonic and hadronic regimes, in nature there exist instances where the low-energy behavior of cross-sections (averaged over appropriate energy intervals) closely resembles that at asymptotically high energies, calculated in terms of quark-gluon degrees of freedom. This

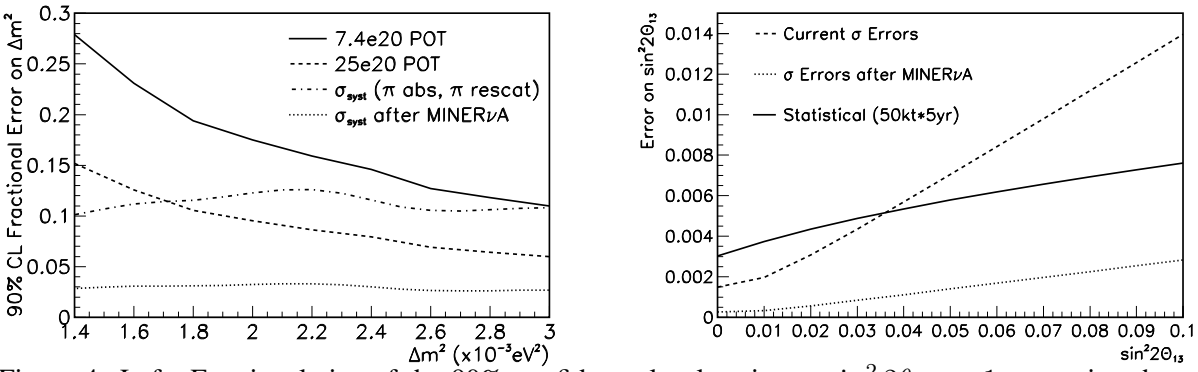

Figure 4: Left: Fractional size of the 90% confidence level region at $\sin^2 2\theta_{23} = 1$, assuming the nuclear effect uncertainties are at their current level, and after MINERνA measurements. Right: Statistical error, current cross-section systematic errors, and post-minerva cross-section systematic uncertainties in a NOνA measurement of $\sin^2 2\theta_{13}$, as a function of $\sin^2 2\theta_{13}$.

phenomenon is referred to as *quark-hadron duality* and is the focus of substantial recent interest in probing the structure of the nucleon [27, 28, 29, 30, 31]. For example, there are over 10 related experiments at JLab.

Understanding this transition requires reliable data in three kinematic regimes: in the scaling domain of high Q^2 DIS scattering; in the hadronic region of resonances and quasi-elastic scattering; and, perhaps most importantly, in the moderate Q^2 region between the two, where the transition is most dramatically manifest. MINERνA is uniquely situated to address this compelling topic for the first time with neutrinos and measurements spanning all three regimes, providing reliable data in the crucial transition region [32].

Finally, once in the perturbative QCD regime, the evolution of parton distribution functions (pdf's) takes high-x$_{Bj}$ pdf's at low Q^2 and evolves them down to moderate-and-low x at higher Q^2. This means that one of the larger contributions to background uncertainties in, for instance, LHC measurements, will be the very poorly-known high-x pdf's at the lower Q^2 values accessible with the NuMI beam. MINERνA will run in the optimal kinematic region and will yield the statistics necessary to begin addressing this important concern.

1.6 Impact of MINERνA's Results on Neutrino Oscillation Studies

The MINERνA studies of nuclear effects and low-energy neutrino cross-sections have direct and important applications to neutrino oscillation experiments such as the MINOS ν_μ disappearance experiment and the future T2K and proposed NOνA ν_e appearance searches.

For MINOS the final observed energy may be significantly lower than the incoming neutrino energy [17, 18]. Since determination of Δm^2 depends on knowledge of the *incoming* E$_\nu$, understanding this energy distortion is crucial for a precise Δm^2 determination. For T2K and NOνA, knowledge of the coherent and resonant π^0 background as well as the signal processes are essential. To better understand how MINERνA's results would improve neutrino oscillation experiments, a preliminary quantitative study [33] has been performed.

Figure 4 summarizes two results from this study. The left plot shows the statistical error for the MINOS Δm^2_{23} measurement as a function of Δm^2_{23}, as well as the systematic uncertainty assuming the current unsatisfactory knowledge of nuclear effects in neutrino reactions subject to pion absorption and rescattering in the nucleus. The right plot shows the statistical and systematic error on $\sin^2 2\theta_{13}$ for NOνA as a function of $\sin^2 2\theta_{13}$. In both plots two different systematic uncertainties are shown: one assuming the current cross-section uncertainties, the other assuming the reduced uncertainties expected as a result of MINERνA. The importance of these measurements will only be greater as higher statistics runs are realized. Increases in statistics by at least an order of magnitude past the current generation are necessary in order to search for CP violation and a determination of the neutrino mass hierarchy through precise ν_e and $\bar{\nu}_e$ appearance measurements.

1.7 Motivation for Testbeam

For a number of key MINERνA results, such as kinematic measurements to isolate coherent scattering, or measurements of individual final state hadron energies in support of oscillation measurements, it will be key

to understand the response of the detector. Unfortunately there are significant physics uncertainties that affect this, in particular the interactions of pions in the detector.

Pion interactions with nuclei are large and complex. In addition to the usual elastic and quasi-elastic cross sections, the pion can undergo charge exchange, leading to π^0 production for charged pion interactions, or be completely absorbed, leading to only nucleons in the final state. Particularly in the $\Delta(1232)$ resonance region, the cross sections are extremely large. For example, the peak cross section for π^+ on iron is about two barns. A recent review of pion interactions can be found in Ref. [34].

Pion interactions with nuclei were extensively studied at the meson factories - LAMPF, PSI, and TRIUMF from the late 1970's until the early 1990's. The highest energy pions were available at LAMPF with a maximum energy of about 575 MeV. Although higher energy pion beams were available at KEK and BNL, the number of measurements made were very limited. The only measurements above the LAMPF limits were on lithium, beryllium, carbon and calcium [35, 36, 37], with the highest incident pion energy being 860 MeV. The most extensive measurements on heavier nuclei were done at LAMPF with pion energies up to 300 MeV [38], and 500 MeV [39]. Although the uncertainty on the total cross section for heavier nuclei is typically known to 5-10%, the breakdown among the sub-cross sections is known much more poorly, with uncertainties on the absorption cross section typically being 10-20% or more. There are no measurements of the relative contributions of the inelastic and absorption cross sections for pion energies above 500 MeV.

The critical issue for the neutrino measurments planned for MINERνA is the relation between the observed energy and total pion energy. Pions created from neutrino interactions will typically have energies in the few hundred MeV region. The cross sections are so large at that energy range that a large fraction of pions will have inelastic scatters or be completely absorbed before stopping. The measurements of Jones [39] showed that positive pion absorption almost always leads to emission of at least one neutron. Even in carbon, typically more than half the total pion energy is taken off by neutrons. Determination of the relationship between pion total energy and energy observed in the detector is key to determination of the incident neutrino energy in the resonance and deep inelastic scattering region. Even relatively limited statistics measurements would help considerably in the understanding of the detector response to pions.

1.8 The MINERνA Collaboration

The MINERνA collaboration currently consists of 73 nuclear and particle physicists from 17 universities in four countries and two US national laboratories (FNAL and Jefferson Lab). The collaboration members are mostly senior scientists and teaching or research faculty; however, as our prototyping program has ramped up, the number of active students and postdocs on the experiment has increased to six and ten, respectively. The collaborating Universities have a strong record of student training and education, as detailed in Section 3. As construction begins, the collaborating Universities expect to recruit more students at the graduate and undergraduate levels, and commit more postdocs to construction and operation of MINERνA.

Results of Prior NSF Support at the Proposing and Sub-Awardee Institutions

Hampton: Hampton's group is funded under NSF award 0400332 ("Transition to a Quark-Gluon Description of the Nucleon"), in the amount of $597,290. This award began in September 2004, but continues over a decade of NSF support through base grants, three MRIs, a successful CREST program, and a CAREER award. Hampton also boasts an NSF-supported Physics Frontier Center focusing on elementary particle physics. In the last three years, the group published 49 papers in refereed journals, with 18 in *Physical Review Letters*, and presented 50 invited talks at international conferences and seminars. The faculty are spokespersons for 12 approved experiments at JLab. Hampton University, as an historically black college, is a leader in minority education, having doubled the number of African-American physics doctorates awarded in 2001 and 2002, according to AIP statistics.

Minnesota-Duluth: The Duluth group is funded by startup funds and has submitted an NSF RUI grant for operating support which is currently under review.

Pittsburgh: One member of the Pittsburgh group (Dytman) had $\sim$$300K base support through NSF grant PHY-0140116 for the last decade for a significant program of research at Jefferson Lab studying the quark structure of baryons using the CEBAF Large Acceptance Spectrometer (CLAS). Dytman was also co-principal

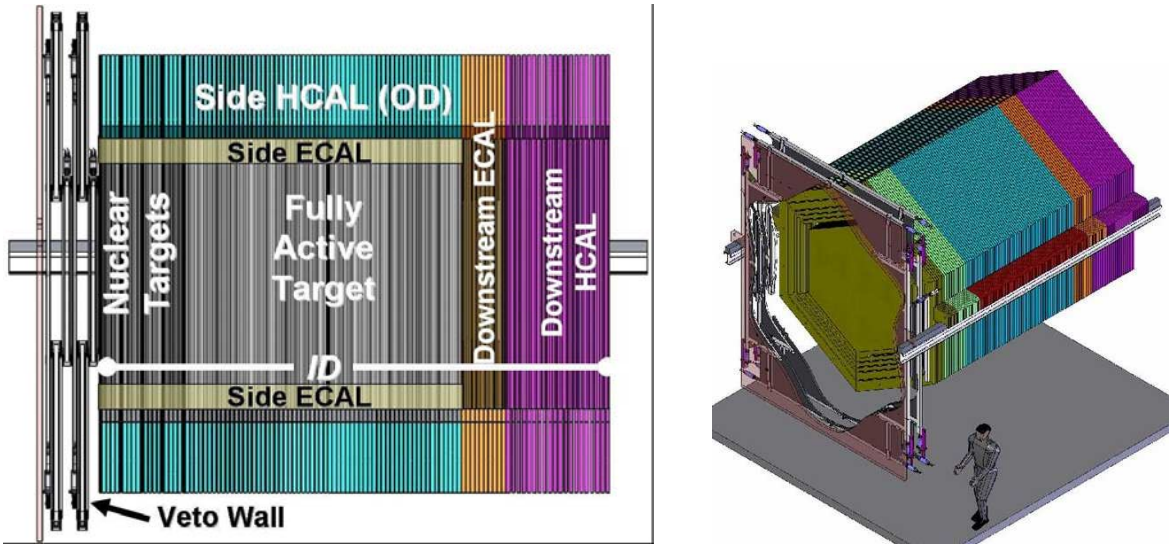

Figure 5: Left: A schematic side view of the full MINERνA detector with sub-detectors labeled. The neutrino beam enters from the right. Right: An isometric view of the detector showing the stand. Note that the baseline detector does not include the cryogenic target which will be installed between the veto wall and nuclear target detector region.

of an NSF Academic Research Infrastructure grant ($\sim$\$1.5M) which funded conversion of the van de Graaf accelerator building to a first class laboratory facility about 12 years ago. This facility was used to build a ($\sim$\$1.0M) drift chamber system for CLAS under Dytman's direction.

Rochester: Although the group is primarily funded by DOE, the group receives support from NSF grant PHY-0242483 ("REU site in physics and astrophysics at Rochester", 7/1/03-present, \$366,008), which supports involvement of undergraduates in the department's research programs, and CAREER award PHY-0134988 ("Precision studies of the top quark and muon telescopes for high school classrooms", 7/1/2002-present, \$220,781 to date), which supports outreach to twenty-five area teachers and over 400 of their students in classroom-based cosmic ray experiments. Co-PI Bodek's achievements in studying the nucleon structure were recently recognized with the 2004 W.K.H. Panofsky Prize. Among other efforts, the co-PIs have been involved in SLAC E-140, CCFRR, AMY, FNAL E-53, SLD and NuTeV. They are currently working on CMS, CDF, T2K, MINERνA and the supporting JUPITER (E04-001) program at JLab. Collectively, the co-PIs have supervised 28 postdocs, 35 Ph.D. students, and 41 REU students.

William & Mary: The William & Mary Neutrino group is supported by start-up funding and has submitted NSF proposals which are currently under review. Since its inception in 2003, the group's research has produced three peer-reviewed papers on MINOS and Soudan 2 and is training three graduate students, six undergraduates, a high school teacher, and one postdoc. Jeff Nelson is Co-PI for the William & Mary Physics REU/RET site and is coordinator of the new RET program (NSF Award PHY-0453502).

2 Detector Design, Development and Proposed Construction

This section briefly describes the MINERνA detector, summarizes its capabilities, and discusses the different construction subprojects to be supported. More detail on the baseline MINERνA detector can be found in the proposal [1] and elsewhere [40, 41].

2.1 The MINERνA Detector

To meet its physics goals, MINERνA must break new ground in the design of high-rate neutrino experiments. With final states as varied as high-multiplicity deep-inelastic reactions, coherent single-π^0 production and quasi-elastic neutrino scattering, the detector is a hybrid of a fully-active fine-grained detector and a traditional calorimeter [1]. Its essential features are described here.

MINERνA is composed of several sub-detectors with distinct functions in reconstructing neutrino interactions. The fiducial volume for most analyses is the inner "Active Target" shown in Figure 5. This volume is made entirely of the sensitive scintillator strips. The scintillator detector does not fully contain forward and sideways going particles due to its low density and low Z, so the MINERνA design surrounds it with sampling detectors. In these sampling detectors, scintillator strips are intermixed with absorbers. For example, the side and downstream (DS) electromagnetic calorimeters (ECALs) have 2 mm lead foil absorbers. Surrounding the ECALs are the hadronic calorimeter (HCAL) and outer detector (OD) which intersperse scintillator with steel absorber. Upstream of the detector is a veto of steel and scintillator panels to shield MINERνA from incoming soft particles produced upstream in the hall. Downstream of MINERνA is the existing MINOS near detector, which will measure the energy of muons which do not exit through the OD. Finally the nuclear targets region provides a many planes of active scintillator with passive absorbers in order to study interactions on nuclei other than carbon.

The core active element will be extruded scintillator strips read out *via* wavelength-shifting fibers, similar in concept to the recently commissioned K2K SciBar detector[42]. Scintillation light will be recorded by multi-anode photomultiplier tubes (MAPMTs) (Hamamatsu R7600U-00-M64), connected to the wavelength shifting fibers *via* an optical cable system and housed in light-tight "optical boxes" mounted atop the OD. There are three distinct orientations of strips in the inner detector, offset by 60°, and labeled X, U, V, in order to reconstruct three-dimensional tracks. For front-end digitization of the MAPMT signals, a design based on the D0 TRiP ASIC [43] has been developed and tested at FNAL . MAPMTs will be directly mounted on the front-end boards (which also include a Cockroft-Walton high-voltage supply for the tube) to reduce input capacitance to the TRiP amplifiers. Both the pulse-height and time (for identification of strange particles and muon decays) of each hit will be digitized. Digitized signals will be collected by custom VME readout controllers through LVDS chains of twelve front-end boards and transferred to the data acquisition computer over a PCI-VME bridge. Slow control messages will also be exchanged with front-end power supplies over the LVDS readout chains.

2.2 Illustrations of Detector Performance

With the low mass design allowed by the high intensity NuMI beam, MINERνA's response to single particles for exclusive final state identification is more similar to a bubble chamber than to previous high-rate neutrino detectors. MINERνA's performance has been studied extensively in a hit-level simulation, including the photostatistical effects of light collection, a realistic Kalman filter reconstruction package for track and vertex fitting, and particle identification. We base the physics sensitivity studies shown in Section 1 on the results of this simulation.

The fully-active region of the detector has excellent performance for tracking and identification of single particles in the final state, including low-energy recoil protons from low-Q^2 $\nu n \rightarrow \mu^- p$ reactions. Charge sharing between adjacent triangular strips allows excellent spatial resolution. For μ^- from quasi-elastic interactions, the expected hit resolution per detector plane is $\sim$ 3 mm. Fitted tracks from such muons have typical impact parameter and angular resolution of $\sim$ 2 mm and $<$ 9 mrad (Figure 6). Using the (typically short) reconstructed proton track and the muon track from quasi-elastic events, RMS vertex uncertainties of 9 mm and 12 mm are measured in the coordinates transverse and parallel to the beam direction, respectively. Measured energy loss (dE/dx) is an excellent tool for particle identification in MINERνA. For tracks which stop in the inner detector, the charge deposited near the end of the track (corrected for sample length) can be compared with expected curves for $\pi^\pm$, $K^\pm$ and protons.

With the surrounding ECALs for containment, MINERνA's π^0 reconstruction capabilities are excellent. This is essential, since π^0's are a major source of background for ν_e appearance oscillation experiments. As shown in Figure 6, MINERνA's low density and high granularity make it an excellent photon tracker, able to accurately reconstruct the vertex and kinematics even for a coherently-produced π^0 with no accompanying charged tracks. Kinematic reconstruction allows coherent and resonant π^0 production to be distinguished.

2.3 Nuclear Targets

As seen in Figure 5, the upstream portion of the detector consists of a section with scintillator planes like those of the active target interspersed with planes of nuclear targets. These planes, steel, lead and graphite,

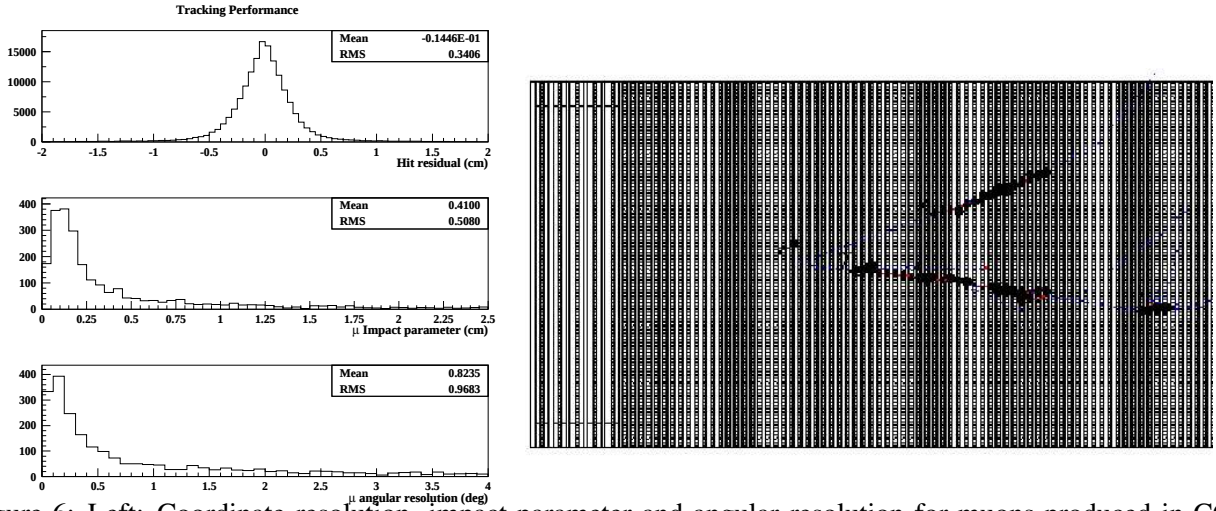

Figure 6: Left: Coordinate resolution, impact parameter and angular resolution for muons produced in CC reactions. Right: A simulated NC coherent π^0 production event in MINERνA (for clarity, the OD is not shown). The π^0 decay vertex can be determined accurately by extrapolating the two photons backward.

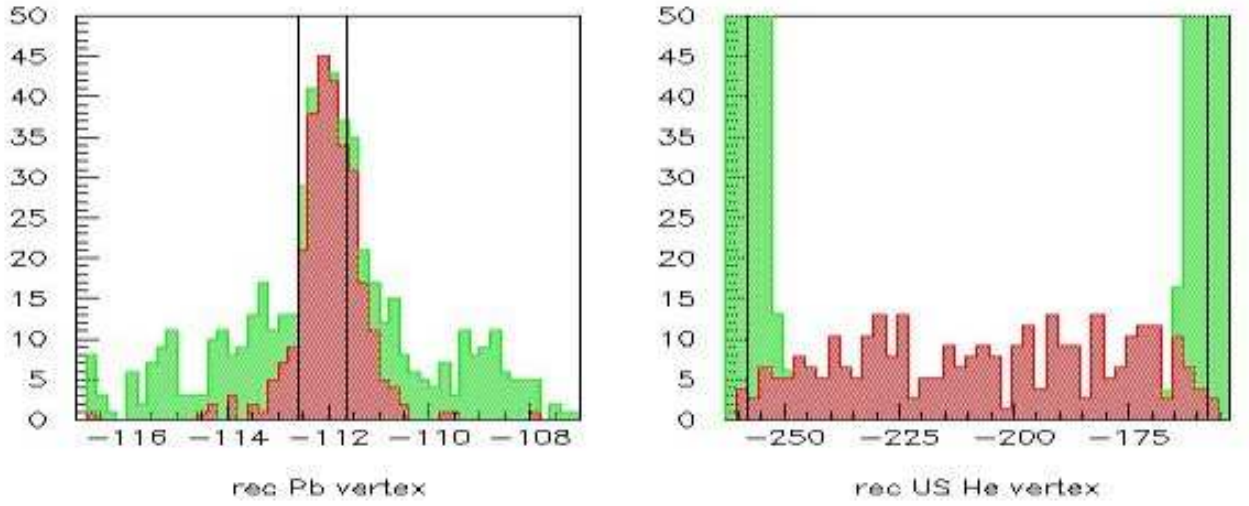

Figure 7: Reconstructed vertex distributions from quasi-elastic events showing the separation of nuclear target (dark red) events from events in the surrounding material (light green). (Left) a thin Pb target; (Right) the He cryogenic target. Note that separation is still possible in the He despite the low density.

will be purchased pre-cut and encapsulated from vendors. At FNAL, they will be installed inside special frames, similar in profile to the OD, which mount on the detector frame with the active scintillator planes. The precise tracking illustrated in Figure 6, gives excellent separation between events originating in the thin nuclear targets and the surrounding material as shown in Figure 7.

The cryogenic target is more technically challenging. The proposed helium target is 1.5 meters in diameter, containing one cubic meter of liquid helium. An inner helium vessel would be surrounded by an outer vacuum vessel, both cylindrical aluminum vessels with dished heads. A 'chimney' would extend from the top of the helium vessel for supports and to provide thermal length for the fill line and cryo instruments. Between these vessels an actively cooled thermal shield would completely surround the helium vessel. The inner helium vessel and the shield would be wrapped with multilayer insulation. The inner vessel and shield supports would be made of Kevlar rope. Kevlar has a good strength to conductivity ratio, and it has been used for supports in cryogenic target and in spaceflight applications. Estimated heat loads are well within the capacity of a single Gifford-McMan cryocooler.

The fill procedure would be to cool down the vessel, either with liquid nitrogen or the cryocooler, then fill

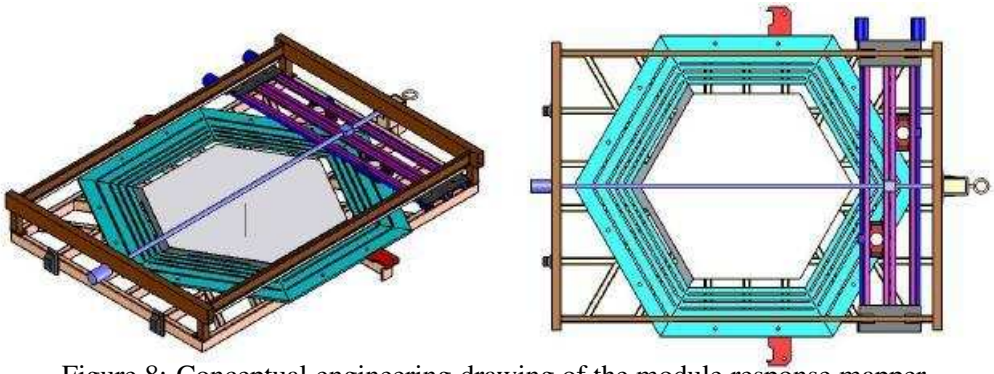

Figure 8: Conceptual engineering drawing of the module response mapper

with liquid helium from dewars. Once filled, the cryocooler would maintain the vessel without losing helium. Medical MRI magnets are about this size and operate in this way.

Fermilab has experience with this type of cryocooler. The target requires less than 60 watts cooling capacity at 55K on the first stage and 1.5 watts at 4.2K on the second stage, which matches commercially available refrigerators. In this case the first stage would be thermally connected with the shield. The second stage would condense helium gas in the vessel. A heater would be used to make sure the helium pressure stayed above atmospheric. Operation is simple and reliable, and the target should run for over one year without maintenance.

Cost estimates for this target system were made by experienced cryogenic engineers at Fermilab and include effort and material and supply costs for the complete cryogenic system. The effort includes vessel design, equipment specification, transfer line design, Fermilab safety documentation, instrument and control configuration, operating procedures and installation.

2.4 Module Response Mapper

We propose to construct a module response mapper to provide quality control of each scintillator element before detector installation and to map the local response of the detector.

Variation in local response is dominated by the attenuation length of the wavelength-shifting fiber. Smaller contributions to the non-uniformity (few%) are expected due the scintillator and the glue coupling the scintillator to the fiber. The mapper measures this variation in response along a given scintillator strip. It also measures the transverse location of each scintillator strip in its installed position relative to an established external fiducial mark. The overall gain for each channel (including PMT response and loss in optical connections) will be determined with cosmic-ray and neutrino-induced muons in the experimental hall.

The mapper will move two collimated sources over the the broad face of the scintillator module, creating scintillation light at known positions. The signal and readout system for the source scanner will be the MINERνA PMTs, PMT boxes and data-acquisition system. The mechanical concept is based on a similar system employed by MINOS. Travel on the short axis is controlled by turning a worm gear, and the long axis mover employs a commercial rack and pinion system similar to those available from Martin Gear. The sources will be moved at 0.15 m/sec along the short axis and 1 m/s along the long axis. Both axes use servo motors such as those manufactured by Aerotek with planetary speed reducers (10:1 for the long axis, 4:1 for the short axis) such as those manufactured by Minarik. The carriage runs on a double side rail bearing combination such as that available from Thompson.

The scanner will employ two 5 mCi Cs-137 sources, which will be provided through the MINERνA project by Fermilab. Collimation will be achieved by a machined lead cone with at least 5 cm of lead on the sides are required for collimation, with at least 2.5 cm of lead on top for shielding. The source will be mechanically connected to the lead cone to prevent removal. Fermilab's Safety Division will review and approve the final design to ensure the shielding is sufficient to protect the scanner operators and others from exposure to hazardous levels of radiation.

2.5 Light Injection

Any particle physics experiment with a large scintillator system such as MINERνA needs a rapid, simple, cost effective monitoring system. MINERνA has over 30,000 scintillators and PMT channels that must be

installed and monitored. The proposed light injection system will be used during installation, before and after maintenance periods, plus regular tests when taking data. This will allow us to measure short term changes to PMT gain during these periods of work and maintenance, especially when installing replacement PMT's. When combined with muon calibrations, we will also be able to infer the long term stability of the scintillator. In the MINOS near detector hall where MINERνA will be located, the temperature is held constant within a 6.5^oF range and the diurnal variation of about 1^oF is seen [44]. The stable environmental conditions simplifies the physics requirements of the light injection system.

The scintillators are read out with wavelength shifting (WLS) fibers which are joined to clear fibers that direct the light to Hamamatsu M64 phototubes (64 pixels per PMT). The PMT's sit in an iron PMT box. A common and simple calibration method is to inject light into the readout fibers. For example, MINOS injects LED light into the WLS fibers at the detector [45]. D0 used a similar method for their muon detectors [46]. In a more novel application, K2K uses an electroluminescent plate to inject light into scintillating fibers [47]. A final method, used by CDF, is to inject light directly into the scintillators using a nitrogen laser.

Our design is a simplified version of the MINOS system. Since our needs are less stringent, we choose to inject LED light into a diffuser in each PMT box. Some of this light will be captured by the clear fibers from the scintillator and detected by the multianode PMT. This will enable a rapid and accurate gain check for the entire PMT. The LED light will be sent to each PMT box and diffuser using its own separate clear fiber from a pulser box near the detector. This box contains optical fanouts, the LED's, and associated electronics. Each pulser box will have 250 fibers funneling light to the PMT boxes; it is the most expensive part of the system. The overall cost is low when compared with the MINOS system.

The MINOS light injection system achieves 2% accuracy with careful attention to construction details and a PIN diode to independently monitor the LED output. Although we don't need as much accuracy, we can easily obtain few percent accuracy with the proposed system. The entire system will be controlled as part of the MINERνA experiment data acquisition program. Groups of PMT's will be pulsed together (like MINOS) and all PMT's and the PIN diodes will be read out each time the calibration system is triggered.

The main use for this system will be to monitor the overall gain of each PMT. MINOS experience [48] shows that the 64 pixels in each PMT drift together. At present, we plan to inject green LED into the ends of the clear fiber. This will provide a good match to the light spectrum for real particles. We are investigating the possibility of also measuring the nonlinearity of the detector response in situ with the light injection system. We would then have to use WLS fiber to properly match the frequency spectrum. Although this additional functionality will put more stringent requirements on the dynamic range of the system, the cost will be the same. Prototyping efforts to date testing LED light coupling to fibers and MINOS experience show that our design will be successful.

2.6 Beam Test

We propose to replicate a small section of the MINERvA detector and operate it in the Fermilab MTest test beam. This detector will be built from shorter pieces of the same scintillator and fiber as MINERvA, and will use the same PMT's and front-end readout electronics as the MINERvA detector.

The primary goal of the test beam is to measure the MINERvA detector response to individual particles, especially protons and pions. This includes information on the total energy of hadronic showers, dE/dx along tracks, energy resolution for both these quantities, shower development topology, and particle ID. We will also take data to calibrate the scintillator quenching effect (Birk's Law) for our scintillator at high dE/dx, which is an input to the detector simulation. These data will allow us to confirm or tune the Geant4 based detector simulation, and calibrate the hadron energy reconstruction. It will also be vital in developing the pattern recognition, and measuring the efficiencies for separating quasi elastic, resonance, and multi-pion production neutrino events. The basic strategy for all these efforts follows the beam tests for the similar SciBar[49] and MINOS[50] detectors.

The absorption and scattering of moderate momentum pions on nuclei is of particular importance to MINERvA physics, and are not well modeled in current Monte Carlo simulations. In addition to the scattering of pions as they travel through the the MINERvA detector, these measurements will support the modeling of rescattering and abosorption of these same pions immediately after the interaction as they leave the target

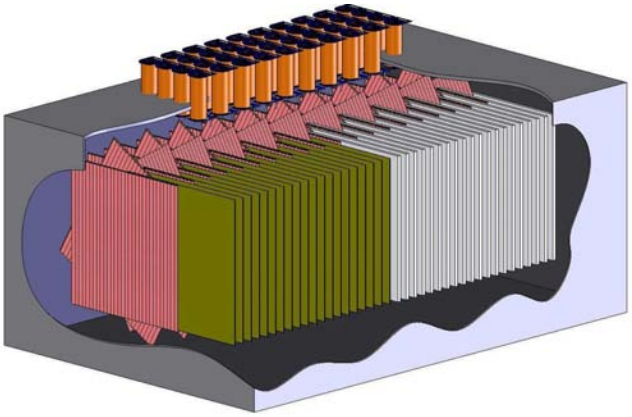

Figure 9: Conceptual engineering drawing of the testbeam detector in the dark box

nucleus. At low energies, this input is needed to understand the acceptance of pions from nuclear resonance reactions, either because of the modified distribution of the pion angle, or because the pion was absorbed, causing the event to be reconstructed as a quasi-elastic event, or because multiple pions exit the nucleus due to rescattering.

2.6.1 Run Plan

The MINERvA detector will be undergoing installation and commissioning at the same time as the test beam runs. Because we will need to return the PMT's and electronics to be installed in the main detector, and because the installation of the main detector will be a significant workload for the collaboration, the duration of the beam test will be short. We plan to take data at several momenta and several configurations representing the main detector, electromagnetic calorimeter, and the hadron calorimeter. In contrast, we plan only a limited set of incident angles and will tune the MC to obtain a description for all angles and for all locations within the detector.

The run plan will include the following configurations:

Pion momenta from 500 MeV to 5 GeV: These runs will be done with different combinations that correspond to the inner tracking detector (scintillator only), and with the addition of steel sheets, the electromagnetic calorimeter and the hadronic calorimeter. These will be done in a head on configuration, and a subset of these pion runs will be done at one other angle.

Proton momenta from 1 to 5 GeV: These will be done at several momenta, with and without the steel absorbers. Only one angle will be used.

Muon momenta around 1 GeV: These will be done for only a few momenta, to obtain the reference one MIP signal in the scintillator. We will also get a sample of stopping muons to calibrate muon decay topologies.

We expect to complete these tests with three weeks of access to the beam, and will need an additional three weeks of staging after all the components are available but before we get access to the beam.

2.6.2 Test Beam Detector

The MINERνA test beam detector will be a smaller version of the MINERνA detector made up of 40 $1.2 \times 1.2 \times 1.8$ m^2 scintillator planes. As in the full detector, the plane will be assembled from nested 33 mm$\times$17 mm triangular-shaped extruded scintillator bars. Each plane will contain 76 1.2 m bars. The scintillator light will be collected by optically coupled 1.2 mm WLS fibers in axial holes through each bar. Successive planes with be rotated by $\pm 60^\circ$ so the scintillators provide alternating three plane readout as with the full detector.

The planes will be constructed as laminates with Lexan skins as in the main detector. They will contain routing pieces to ensure the fibers are constrained and protected as they carry light roughly 1 m to an array of optical connectors. The planes will be mounted in a support structure contained in a light tight box as shown in Figure 9. The optical connectors will penetrate the box on the top and one side and be arranged so they can be directly mated to the production MINERνA readout components.

The detector will be read out with the final production MINERνA components including 50 MAPMTs, HV supplies, front-end electronics, and subset of the full data acquisition system. The readout for the test

beam detector will be implemented using components from the spare elements of the full MINERνA detector are not in the scope of this proposal.

To simulate the various calorimetric regions of the full MINERνA detector, the detector structure will be equipped with absorbers including lead and iron absorbers that can be inserted between the planes.

3 Broader Impact of MINERνA and this Proposal

MINERνA is well-suited to ensure broad impacts and educational opportunities with its construction and physics program. These impacts can be demonstrated by the collaborators' records in graduate training, their involvement in and commitment to undergraduate research, the key role of an historically black institution, and finally a dedicated education and public outreach program proposed as part of this project.

Graduate research is integral to MINERνA. The sheer breadth of MINERνA's physics program is a cornucopia of Ph.D. thesis topics, and the experiment is small enough (by particle physics standards) that individual students can make significant contributions. The construction lead time is short, so students can experience building and operating the experiment as well as physics analysis. Most of the collaborating universities support significant numbers of graduate students in experimental nuclear and particle physics.

MINERνA collaborators also share a commitment to undergraduate student training in the research environment. Every institution in this proposal will support undergraduate research as part of this proposal. All have a proven record of training undergraduates in particle and nuclear physics research and most are active NSF REU sites (Hampton, Pittsburgh, Rochester, William and Mary). Hampton and Minnesota-Duluth are classified as non-Ph.D.-granting institutions, and these groups play a critical role in exposing undergraduates to research in particle and nuclear physics. Eight graduate and undergraduate students from these groups have already contributed to the design of MINERνA or gained hands-on research experience in our vertical slice test, and that number will increase many-fold once construction of the detector begins. The scope of the testbeam program makes it ideal as a student training project, and the leadership of Minnesota-Duluth in that program will maximize this impact by design.

One of the largest contributors to our fabrication effort, Hampton University, is an historically black institution. In 2001, the HU Physics Department graduated over 70% of the African-American Physics PhDs nationally [51]. The first two nuclear physics PhD's to African-American women from an historically black college or university were awarded by Hampton in 2001 and 2002. Through Hampton's central involvement, starting with a key construction role engaging undergraduate and graduate students, this proposal will provide state-of-the-art training for young African-American researchers, who are vastly under-represented in particle and nuclear physics. These opportunities address a national need for diversity in the educational pipeline and growth in programs that can attract African-American students into science to address the troubling fact that African-Americans currently make up less than 10% of the undergraduate science population, under 5% of the graduate population, and less than 2% of the doctoral majors nationally [52].

Finally, to ensure educational impact of MINERνA beyond the collaborating universities in this proposal, we have conceived an education and outreach program to complement the construction effort. The simple, relatively inexpensive, and modular design of MINERνA, and the striking, intuitive appearance of particle tracks passing through it, lend themselves as a vehicle for teaching and demonstrating the principles of physics on which it relies. The uncanny properties of neutrinos provide a perfect "hook" to engage the curiosity of students and the general public. Our program will have two components, the first of which is completely funded by this proposal, and the second of which is initiated by this proposal and completed in collaboration with UC-Irvine, another MINERνA collaborating institution.

3.1 Mini-MINERνA

Rochester will host a team of undergraduates, a secondary school teacher and students, and a graduate student for one summer to develop a small version of an extruded scintillator strip detector (Mini-MINERνA) to demonstrate the detection of cosmic rays. This working model has been successful in the past in the Rochester PARTICLE program where student-teacher teams have refurbished and done cosmic ray studies with large area scintillator panels intended for the MINERνA veto wall. To bypass computerized data acquisition, mini-MINERνA will not use the MINERνA MAPMTs and front-end electronics, but rather a multi-stage image

intensifier connected to a camera. The teacher and students will be recruited from those currently involved with the Rochester PARTICLE program [53], and initial use of the Mini-MINERνA detector would focus on serving as a demonstration apparatus for classroom visits as part of PARTICLE. Equipment funds are requested for the image intensifier and camera, but other materials for the project as well as modest technician and machining support will be obtained from scrap materials and existing technical staff supported in the process of constructing MINERνA.

3.2 Mobile-MINERνA

Taking "Mini-MINERνA" one step further, we will build five additional miniature cosmic-ray detectors (each consisting of several planes, with 64 strips total) based the multi-anode PMTs used in the detector and prototype digitizer boards interfaced to desktop or laptop computers. As with Rochester's Mini-MINERνA project, most components for the portable detectors can be collected from material left over from construction. Assembly of the detector strips and MINERνA PMT-box compatible dark boxes will be completed at Rochester and funded by this proposal. Integration with the MINERνA test electronics and spare dark boxes will be completed by UC-Irvine collaborators from separate funding.

We will distribute these portable "Mobile-MINERνA" detectors among the participating institutions and laboratories for demonstrations to enrich on-going outreach and educational activities. One of the MINERνA collaborating institutions, UC-Irvine, for instance, leads an NSF-supported "assemblies" program of K-12 outreach to predominantly Latino and African-American schools in the Los Angeles area. A Mobile-MINERνA detector could be integrated with the project's Modern Physics and Optics demonstrations and reach dozens of public schools every year. UCI also hosts popular and well-attended open nights at the campus observatory, where the detector could demonstrate cosmic-rays and introduce visitors to neutrino physics. Other collaborating institutions, of course, sponsor similar activities. The detectors could also be used by the Fermilab and JLab Visitor's Centers, and as classroom lecture demonstrations at universities.

4 Management Plan: MINERνA and this Proposal

MINERνA has a mature detector design and construction and installation plan and has received Stage I (physics) approval from Fermilab. The technical design and construction plan went through two successful Fermilab internal ("Temple") reviews in January 2005 [41] and December 2005 [54]. The latter demonstrated the readiness of FNAL MINERνA construction project for DOE CD-1 approval. Stage II (baseline) approval of the project is planned for summer 2006. Technical feasibility of the detector design has been demonstrated by an active R&D program focused on design and prototyping of all elements.

This proposal seeks to fund a portion of MINERνA focusing on nuclear targets and calibration including many elements beyond the baseline of the current MINERνA construction project. To provide funding for the remainder of the detector, Fermilab has submitted a request to the DOE for an Major Item of Equipment (MIE). Substantial funds have already been provided in FY05 from Fermilab's operating budget to carry out the scheduled R& D program of the baseline detector. In this section, we summarize the management of the MINERνA project, describe the proposed interaction between this proposal and the project, and detail the deliverables for items in this proposal.

4.1 Management of the MINERνA Project

To ensure effective organization and management of the project, which is distributed across many universities and the host lab, the project is coordinated by the Project Manager (PM), who is appointed by the Fermilab Directorate. The PM reports on R& D and construction progress bi-weekly to a Project Management Group (PMG) established by the Fermilab Directorate. The PMG consists of representatives from the Fermilab Directorate, Business Office, and the Particle Physics Division. The project manager's responsibilities include quarterly progress reports on milestones and expenditures to Fermilab, *via* a project management group (PMG), and to all funding agencies supporting the project.

The MINERνA detector components are categorized into nine different sub-tasks (Table 1), and the Project Manager assigns responsibility to nine different Level 2 Managers for completion of those components. Eight of the subsystems have Level 2 Managers from collaborating Universities, and where needed, there is also a Level-2 (co-)manager at Fermilab to oversee safety responsibilities. Weekly meetings with the

Project	L2 WBS ID	Related Items in This Proposal
Scintillator	1	Scintillator for Testbeam Detector (Rochester)
WLS Fiber	2	Fiber for Testbeam Detector (Rochester)
Scintillator Plane Assembly	3	Scintillator Planes for Testbeam Detector (W& M)
Clear Fiber	4	
PMT Boxes	5	Light Injection System (Pittsburgh)
PMT Procurement and Testing	6	
Electronics and DAQ	7	
Frames, Absorbers and Stand	8	Solid Nuclear Targets (Rochester)
Frames, Absorbers and Stand	8	Cryogenic Target (Hampton)
Module Assembly	9	Testbeam Module Assembly (Rochester)

Table 1: The WBS structure of the FNAL MINERνA project at Level-2 and Interactions with this proposal. Minnesota-Duluth delivers no component but plays a key role in testbeam operations.

Item	Quantity	Institution	Initial Prod.	Final Prod.	Delivered to
Scint. Bars	3040	Rochester	3/20/07	3/26/06	W&M
WLS Fibers	3040	Rochester	3/28/05	7/9/06	W&M
Scint. Planes	40	W&M	6/04/06	8/30/07	FNAL
Pb Testbeam Absorbers	20	Rochester	1/8/07	3/27/07	FNAL
Fe Testbeam Absorbers	20	Rochester	1/8/07	2/27/07	FNAL
Graphite Targets	2	Rochester	1/8/07	3/27/07	FNAL
Pb Targets	3	Rochester	1/8/07	3/27/07	FNAL
Fe Targets	3	Rochester	1/8/07	2/27/07	FNAL
Cryo. Target and Controls	1	Hampton	6/1/06	9/14/07	FNAL
Light Injection System	1	Pittsburgh	6/1/06	8/30/07	FNAL

Table 2: Deliverables supported by the development funds from this proposal, not including spare and waste quantities. Items delivered to FNAL are for installation.

Level 2 Managers are held to ensure that the schedule is being maintained, and if extra coordination or effort is needed it can be provided.

4.2 Interaction between the MINERνA Project and this proposal

The deliverables provided by this proposal (Table 2) will be incorporated into the MINERνA management structure to ensure the success of the extended program described here. Work done to provide the deliverables would be entered into the resource-loaded schedule, and would comprise part of the MINERνA Project. As such, the Project Manager would monitor and report on the progress to Fermilab of these parts of the detector along with the baseline detector components. These reports will be made available to the PIs of this grant and to NSF upon request.

4.3 MINERνA and this Proposal: Data Collection and Operations

Once commissioned, data obtained by MINERνA including the elements of this proposal will be shared by the entire collaboration. In addition, the close proximity of the MINOS experiment's near detector may make it desirable to provide MINERνA data to MINOS, and vice versa, for events extending from MINERνA into the MINOS detector. This exchange of data is technically possible with our design, and MINOS and MINERνA expect to completed MOUs with FNAL covering this point in calendar year 2006.

Operation and support of the completed detector, including the elements supported in this proposal will be the responsibility of the MINERνA Collaboration and the host lab, FNAL, as appropriate. Personnel to provide these tasks, as well as analyze the data, will be supported from operating grants of the collaborating institutions and Fermilab.

References

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Biographical Sketch of Kevin Scott McFarland

(a) Professional Preparation

Brown Univ.	Physics	Sc.B. 1989
Univ. of Chicago	Physics	M.Sc. 1991
Univ. of Chicago	Physics	Ph.D. 1994

(b) Appointments

Professor of Physics, Univ. of Rochester, 2005-present
Associate Professor of Physics, Univ. of Rochester, 2002-2005
Assistant Professor of Physics, Univ. of Rochester, 1998 - 2002
CDF Offline Coordinator (Guest Scientist), Fermilab, 2000 - 2002
Leon M. Lederman Fellow, Fermilab, 1994 – 1998

Fellowships and Honors:

Fellow, American Physical Society, 2005
National Science Foundation CAREER Award, 2002
Cottrell Scholar Award, Research Corporation, 2001
DOE Outstanding Junior Investigator Award, 1999
Alfred P. Sloan Foundation Research Fellow, 1998
Nathan Sugarman Award for Outstanding Graduate Research, Enrico Fermi Institute, University of Chicago, 1992
National Science Foundation Graduate Fellow, 1989-1992
McCormick Fellow, University of Chicago, 1989-1993

(c) Selected Publications (of more than 200)

1. A search for muon-neutrino to electron-neutrino and muon anti-neutrino to electron anti-neutrino oscillations at NuTeV, Phys. Rev. Lett. 89 (2002)
2. A precise determination of electroweak parameters in neutrino-nucleon scattering Phys. Rev. Lett. 88 (2002) 091802.
3. Precise measurement of dimuon production cross-sections in nu/mu Fe and anti-nu/mu Fe deep inelastic scattering at the Tevatron, Phys. Rev. D64 (2001)112006.
4. Measurements of F2 and xF3(nu) – xF3(anti-nu) from CCFR nu/mu Fe and anti-nu/mu Fe data in a physics model independent way, Phys. Rev. Lett. 86 (2001) 2742.
5. Neutrino mass and oscillations, Ann. Rev. NS49 (1999) 481.

(d) Synergistic Activities

1. Leader and Co-PI, PARTICLE project (high school teachers and students), University of Rochester, 1999-present. http://www.pas.rochester.edu/particle/
2. Member, HEPAP Sub-Panel on Long-Range Planning for US High Energy Physics (Bagger/Barish sub-panel), 2001.
3. Co-Leader, CDF Offline Computing. 2000-2002.
4. Leader, CDF Level-3 PC Farm Project, a collaboration at Fermilab between computer scientists and physicists to adapt a scalable commercial PC farm architecture to high-rate, realtime data acquisition and processing applications, 1997-2000.
5. Co-author, Fermilab Visitor Area permanent exhibition on Particle Physics discoveries at Fermilab

(e) Collaborators and Other Affiliations

Collaborators:

Members of the MINERvA Collaboration at Fermilab
Members of the CDF Collaboration at Fermilab (450 physicists)
Members of the NuTeV Collaboration at Fermilab (35 physicists)
Members of the E799/E773 Collaborations at Fermilab (40 physicists)
Prof. Peter Fisher, Massachusetts Institute of Technology
Dr. Boris Kayser, National Science Foundation

PI's Graduate and Postdoctoral Advisors:

Prof. Yau Wah, University of Chicago
Dr. Robert Bernstein, Dr. Jeffrey Appel, Fermilab.

Graduate (10) and Postdoctoral Advisees (5):

Dr. Veronique Boisvert, Dr. Robert Bradford, Dr. Gilles deLentdecker,
Dr. Kirsten Tollefson, Dr. Anthony Vaiciulis, University of Rochester
Mr. Jesse Chvojka, Dr. Sarah Demers Konezny, Mr. Bo-Young Han,
Dr. Benjamin Kilminster, Mr. Jedong Lee, Mr. Jaewon Park,
Ms. Jennifer Seger
University of Rochester
Mr. Konstantin Anikeev, Dr. Jonathan Miller, Dr. Alexander Rakitin,
Massachusetts Institute of Technology

Undergraduate students supervised since 2001: 17

Biographical Sketch of Arie Bodek

Professional Preparation & Education

Mass Inst. Tech (MIT)	Physics	BS. 1968
Mass Inst. Tech (MIT)	Experimental Particle Physics	Ph.D. 1972
MIT Laboratory for Nuclear Science	Research Assoc., Electron Scattering	1972-1974
Caltech	Millikan Fellow, Neutrino Physics	1974-1976

Appointments

Chair, Dept of Physics and Astronomy, Univ. of Rochester	1998- present
Assoc. Chair, Dept of Physics and Astronomy, Univ. of Rochester	1995-1998
Physicist, Department of Energy, Washington DC	1990-1991
Professor of Physics, University of Rochester, NY	1987-
NSF-JSPS Fellow (TRISTAN-KEK, Japan)	1986-1987
Associate Professor of Physics, University. of Rochester	1980-1987
Assistant Professor of Physics, University of Rochester	1977-1980

Five Relevant Publications

1) A. Bodek and U.K. Yang, Modeling Neutirno and Electron Scattering Cross-sections in the few GeV region with Effective LO PDFs. AIP Conf. Proc. 670: 110, 2003
2) .U.K. Yang et al. (CCFR/NuTeV collaboration) Measurment of Nucleon Structure Functions in Neutrino Scattering Experiments , Phys.Rev.Lett.86:2742,2001
3) U.K. Yang, A. Bodek, Parton Distributions d/u and Higher Twist Effects at high x. Rev.Lett.82:2467,1999
4) S. Dasu et al, Precision Measurement of R and F2 in Deep Inelastic Electron Scattering, Phys. Rev. Lett 61: 1061, 1988.
5) Arie Bodek et al., Experimental Studies of the Neutron and Proton Electromagnetic Structure Functions Phys. Rev. D20, 1471 (1979).

Five Additional Publications (of more than 600 in High Energy Physics)

6) F. Abe et all, Limits on Quark-Lepton Compositeness Scales from Dileptons Produced in 1.8 TeV p-anti-p Collisions, Phys. Rev. Lett 79: 2198, 1997.
7) F. Abe et al., A Measurement of the Lepton Charge Assymmetry in W Boson Decays Produced in p anti-p Collisions, Phys. Rev. Lett 81: 5754, 1998.
8) Q. Fan, and A. Bodek, A New Techniques for Determining Charge and Momentum of Electrons and Positrons using Calorimetry and Silicon Tracking, in Frascati 1996, Calorimetry in High Energy Physics.
9) F. Abe et al., (CDF Collaboration), Observation of Top Quark Production in Anti-p p Collisions with the Collider Detector, Phys.Rev.Lett.74:2626,1995
10) D. Stuart et al., (AMY Collaboration), Measurements of R for e+e- Annihilations at TRISTAN Phys. Rev. Lett. 64, 983 (1990).

Synergistic Activities, Awards and Honors

American Physical Society Panofsky Prize in Experimental Particle Physics (2004)
University of Rochester Award for Excellence in Graduate Teaching (2004)
Fellow, American Physical Society (1985-)

Listed on ISI as highly cited researcher (2004)
US-Japan NSF JSPS Fellow (TRISTAN – 1984)
Alfred P. Sloan Foundation Fellow (1976)
Robert E. Millian Fellow (1974-1977)
U.S. Editor, European Physics Journal (1992-)
Co-director, NSF REU (Research Experience for Undergraduates) – Rochester (1994-)
Spokesperson for the Principle Investigators Rochester High Energy Group (1987-1998)
Director of GAANN Fellowship in Physics, University of Rochester (1994-)
Director of Undergraduate Studies, Laboratory Coordinator (1992-1998)
Department of Energy Review Committee of the Stanford Linear Accelerator (1999-2000)
Spokesperson, Fermilab Experiment E595 (Hadronic Charm Production)-experiment completed
Deputy Spokesperson Fermilab Experiment E701 (Neutrino Oscillations)-experiment completed
Co-Spokesperson, SLAC Experiment E140, E140x (Electron Scattering)-experiment completed
Co-Spokesperson, JUPITER electron scattering experiment (Jefferson lab) data-taking 2004-2005
Rochester Institution Representative – CDF collaboration
Rochester Institutional Representative – CMS collaboration

Collaborators and Other Affiliations in Past Years
JUPITER collaboration at Jefferson Lab (since 2002)
MINERvA Collaboration at Fermilab (since 2002)
CMS Collaboration at LHC at CERN (since 2000)
The CDF Collaboration at Fermilab (since 1989)
CCFR/NuTeV Collaboration at Fermilab (since 1981)
The AMY Collaboration at TRISTAN, the E595 Collaboration at FNAL (distant past)
SLAC E139, E140 and E140X Collaboration (distant past)

Post-doctoral Advisors
Professor Barry Barish, and Professor Frank Sciulli (Caltech)

Graduate Thesis Advisors
Professor Henry W. Kendall and Professor Jerome I Friedman (MIT 1972)

Postdoctoral Researchers Supervised (16)
D. Harris, B. Winer, L. Chinitz, R. Coleman, N. Giokaris, S. Kanda, B.J. Kim, W. Marsh, A. Sill, K.Ueno, R.Walker, H.W. Zheng, H. Budd, P. de Barbaro, W. Sakumoto, Y. Chung

Graduate Students Ph.D. Research Supervisor (16) (degree date)
R. Breedon (1983,MS), J. L. Ritchie (1983), I. E. Stockdale (1984), K.Lang (1985), S. R Dasu (1988), P. de Barbaro (1990), T. Kumita (1990), Y. K. Li (1991), M. Dickson (1994), B. J. Kim (1994), C. Velissaris (1995), M. Pillai (1996), Q. Fan (1997),J. B. Liu (2000), U.K. Yang (2000), S. Avvakumov (2001)
Current Graduate Students: J. Han, P. Yoon, G. Yu

Biographical Sketch of Howard Scott Budd

A. Professional Preparation

Pennsylvania State Univ.	Physics/Mathematics	B.S. 1971
Univ. of Illinois at Urbana	Mathematics	M.S. 1972
Univ. of Illinois at Urbana	Experimental HEP	Ph.D. 1983

B. Appointments

Senior Scientist, Univ. of Rochester 2003 - present
Senior Research Associate, Univ. of Rochester 1987 - 2003
Research Associate, Univ. of Rochester 1983-1987

C. Publications

A search for muon neutrino to electron neutrino and overline muon neutrino to overline electron neutrino oscillations at NuTev, Phys. Rev. Lett. 89 (2002) 011804.

A precise determination of electroweak parameters in neutrino nucleon scattering, Phys. Rev. Lett. 88 (2002) 091802.

Precise measurement of dimuon production cross-sections in nu/mu Fe and anti-nu/mu Fe deep inelastic scattering at the Tevatron, Phys. Rev. D64 (2001) 112006.

Measurements of F2 and xF3(nu) □xF3(anti-nu) from CCFR nu/mu Fe and anti-nu/mu Fe data in a physics model independent way, Phys. Rev. Lett. 86 (2001) 2742.

Modeling quasielastic form-factors for electron and neutrino scattering, to be Published in Nucl. Phys. B.

D. Synergistic Activities

CCFR Neutrino Experiment E744 & E770 at FNAL
Amy Experiment at TRISTAN, Japan
CDF Experiment at FNAL
NuTeV Experiment E815
CMS Experiment
MINERvA Experiment
Neutrino Physics

E. Collaborators and Affiliations

Members of the CMS Collaboration at CERN (HCal group)
Members of the MINERvA Collaboration at Fermilab
Members of the CDF Collaboration at Fermilab (450 physicists)
Members of the NuTeV Collaboration at Fermilab (35 physicists)

Graduate Advisor
L. Koester (deceased)
Postdoctoral Advisors
A. Bodek (Univ.of Rochester), S. Olsen (Hawaii)

Steven Laurens Manly

(a) Professional Preparation

Pfeiffer College, Misenheimer, NC,	chem/math/phys	B.A. (1982), summa cum laude
Columbia University,	particle physics	Ph.D. (1989)
Yale University,	particle physics	Postdoc (1988-1990)

(b) Appointments:

Univ. of Rochester	Associate Professor of Physics (July 1998 - present)
Univ. of Rochester	Mercer Brugler Distinguished Teaching Professor (2002-2005)
Yale University	Associate Professor of Physics (1996 - 1998)
	Assistant Professor of Physics (1990 - 1996)

Awards:

New York State Professor of the Year 2003 (Carnegie Foundation for the Advancement of Teaching)

(c) Selected Publications (of more than 85 referred publications):

1. *Energy dependence of elliptic flow over a large pseudorapidity range in Au+Au collisions at RHIC,* Phobos Collaboration, B. Back et al., Phys. Rev. Lett. 94. 122303 (2005);
2. *Energy dependence of particle multiplicities in central Au-Au collisions,* Phobos Collaboration, B. Back *et al.,* Phys. Rev. Lett. **88**: 022302, 2002;
3. *Experimental feasibility of measuring the gravitational redshift of light using dispersion in optical fibers,* S. Manly, E. Page, Phys. Rev. **D63**:062003, 2001;
4. *Measurement of the average B hadron lifetime on Z decays using reconstructed vertices*, SLD collaboration, Phys. Rev. Lett. 75, 3624 (1995);
5. *ν_μ-ν_e universality in charged-current neutrino interactions*, N.J. Baker et al., Phys. Rev. **D 41**, 2653 (1990).

(d) Synergistic Activities:

Substantial use of collaborative learning techniques in large introductory physics courses; chair of departmental graduate and undergraduate teaching assistant training committee (1999-present); chair of cross-disciplinary taskforce on use of collaborative teaching techniques (2000-2004); chair of College Teaching Learning and Technology Roundtable (2003-present); referee for Phys. Rev. D, Physical Review Letters, Mod. Physics A and DOE; served on NSF Distinguished Teaching Scholar selection panel.

(e) Collaborators and other affiliations:

High Energy and Nuclear Physics (collaborator list link is included)

- **Phobos collaboration** (1992-present) – Heavy ion experiment at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory – http://phobos-srv.chm.bnl.gov/
- **Neutrino physics** (2002-present) – Minerva experiment at FNAL – http://www.pas.rochester.edu/~ksmcf/minerva/

- **CLAS collaboration/electron scattering** (2003-present) – Work aimed at understanding low energy electron and neutrino cross sections and nuclear effects on the nucleon - http://www.jlab.org/Hall-B/
- **SLD collaboration** (1985-1998) - Experiment to study decay of Z bosons in e^+e^- collisions at the Stanford Linear Accelerator Center - http://www-sld.slac.stanford.edu/sldwww/sld-working.html
- **ILC -** International Linear Collider (1994-1996, currently not active) - 0.5-1.5 TeV e^+e^- collider undergoing conceptual design studies.
- **E53 collaboration** (1985-1990) - Heavy liquid bubble chamber experiment at Fermi National Laboratory. *Neutrino universality; Dilepton production by neutrinos.*
- ***Gravitational Physics***
- *Exploring gravitational effects on light in optical fiber (collaborator – Eric Page)*

Graduate and postdoctoral advisors:
Graduate advisors – C. Baltay and M. Shaevitz (Columbia University)
Postdoctoral advisor – C. Baltay (Yale University)

Supervised research since 1999:

- **Undergraduates:** ***At University of Rochester* – David Sher** – *electron scattering physics, presently at John's Hopkins*; **Garret Mason –** *heavy ion physics, presently at Colgate*, **Cliff Cheung, -** *heavy ion physics, presently in graduate school at Harvard*, **Jennifer Ellsworth** – *heavy ion physics, B.S. from Columbia, now in graduate school at M.I.T.*, **Peter Allen** - *heavy ion physics, B.S from UR*; **John Vernaleo** - *heavy ion physics, B.S. from UR*; **Alysse DeFranco** - *heavy ion physics, B.S. from UR*; **Jeff Clark** - *gravitational physics, B.S. from UR*; **Daniel Kerr** - *gravitational physics*, B.S.from SUNY, Albany.
- **Graduate students:** ***At University of Rochester* - Eric Page** – Ph.D. 2005 on measurement of gravitational redshift of light and effects on soliton propagation in optical fibers presently teaching at Allegheny College; **Josh Hamblen** – Ph.D. work in progress, topic: elliptic and directed flow in ultrarelativistic heavy ion collisions; Peter Walters – Ph.D. work in progress on comparison of elliptic and directed flow in ultrarelativistic heavy ion collisions of different species; **Adam Harrington** – M.S. 2004: comparison of elliptic flow in the fragmentation region of heavy ion collisions.
- **Postdocs:**. ***At University of Rochester* - Inkyu Park**, *heavy ion physics*, professor at University of Seoul.

Biographical Sketch for Dr. M. Eric Christy

(i) **Professional Preparation**

Northern Kentucky University	Physics/Mathematics	B.S. 1991
University of Kentucky	Physics	M.S. 1993
University of Kentucky	Physics	Ph.D. 1999
Hampton University	Nuclear Physics	Postdoctoral Associate 1999-2003

(ii) **Appointments**

Hampton University	Asst. Professor of Physics	Fall 2003 - Present

(iii) **Publications**

[Jefferson Lab E94110 Collaboration] Y. Liang, M,E. Christy, A. Ahmidouch, C.S. Armstrong, J. Arrington, R. Asaturyan, S. Avery, O.K. Baker, D.H. Beck, H.P. Blok, C.W. Bochna, W. Boeglin, P. Bosted, M. Bouwhuis, H. Breuer, D.S. Brown, A. Bruell, R.D. Carlini, J. Cha, N.S. Chant, A. Cochran, L. Cole, S. Danagoulian, D.B. Day, J. Dunne, D. Dutta, R. Ent, H.C. Fenker, B. Fox, L. Gan, H. Gao, K. Garrow, D. Gaskell, A. Gasparian, D.F. Geesaman, R. Gilman, P.L.J. Gueye, M. Harvey, R.J. Holt, X. Jiang, M. Jones, C.E. Keppel, E. Kinney, W. Lorenzon, A. Lung, D.J. Mack, P. Markowitz, J.W. Martin, K. McIlhany, D. McKee, D. Meekins, M.A. Miller, R.G. Milner, J.H. Mitchell, H. Mkrtchyan, B.A. Mueller, A. Nathan, G. Niculescu, I. Niculescu, T.G. O'Neill, V. Papavassiliou, S.F. Pate, R.B. Piercey, D. Potterveld, R.D. Ransome, J. Reinhold, E. Rollinde, O. Rondon, P. Roos, A.J. Sarty, R. Sawafta, E.C. Schulte, E. Segbefia, C. Smith, S. Stepanyan, S. Strauch, V. Tadevosyan, L. Tang, R. Tieulent, V. Tvaskis, A. Uzzle, W.F. Vulcan, S.A. Wood, F. Xiong, L. Yuan, M. Zeier, B. Zihlmann, V. Ziskin "Measurement of $R = \sigma_L/\sigma_T$ and the separated longitudinal and transverse structure functions in the nucleon resonance region," submitted to Phys. Rev. Lett.

I.A. Qattan, J. Arrington, R.E. Segel, X. Zheng, K. Aniol, O.K. Baker, R. Beams, E.J. Brash, J. Calarco, A. Camsonne, J.-P. Chen, M.E. Christy, D. Dutta, R. Ent, S. Frullani, D. Gaskell, O. Gayou, R. Gilman, C. Glashausser, K. Hafidi, J.-O. Hansen, D.W. Higinbotham, W. Hinton, R.J. Holt, G.M. Huber, H. Ibrahim, L. Jisonna, M.K. Jones, C.E. Keppel, E. Kinney, G.J. Kumbartzki, A. Lung, D.J. Margaziotis, K. McCormick, D. Meekins, R. Michaels, P. Monaghan, P. Moussiegt, L. Pentchev, C. Perdrisat, V. Punjabi, R. Ransome, J. Reinhold, B. Reitz, A. Saha, A. Sarty, E.C. Schulte, K. Slifer, P. Solvignon, V. Sulkosky, K. Wijesooriya, B. Zeidman, "Precision Rosenbluth measurement of the proton elastic form factors," Phys. Rev. Lett. **94**, 142301 (2005).

M. E. Christy *et al.* [Jefferson Lab E94110 Collaboration], "Measurements of electron proton elastic cross sections for $0.4 < Q^2 < 5.5$ $(\mathrm{GeV/c})^2$," Phys. Rev. C **70**, 015206 (2004)

V. Tvaskis, J. Arrington, M. E. Christy, R. Ent, C. E. Keppel, Y. Liang and G. Vittorini, "Experimental constraints on non-linearities induced by two-photon effects in elastic and inelastic Rosenbluth separations," accepted for publication in Phys. Rev. C.

G. Warren *et al.* [Jefferson Lab E93-026 Collaboration - see supporting documents], "Measurement of the electric form factor of the neutron at $Q^2 = 0.5$ $(GeV/c)^2$ and 1.0 $(GeV/c)^2$," Phys. Rev. Lett. **92**, 042301 (2004).

M. Osipenko, S. Simula, W. Melnitchouk, P. Bosted, V. Burkert, E. Christy, K. Griffioen, C. Keppel, S. Kuhn, G. Ricco, "Global analysis of data on the proton structure function g1 and extraction of its moments," Phys. Rev. D **71**, 054007 (2005).

M. Osipenko, W. Melnitchouk, S. Simula, P. Bosted, V. Burkert, M.E. Christy, K. Griffioen, C. Keppel, S.E. Kuhn, "Higher twist analysis of the proton g1 structure function," Phys. Lett. B **609**, 259 (2005).

(iv) **Synergistic Activities**

Participated as a mentor in the Hampton University Undergraduate Physics Institute (UNIPHY) program during the summers of 2000 - 2005. This entailed supervising students participating in summer research for undergraduates, some of which were from Historically Black Universities and Colleges (HBCUs) such as Hampton University. Have also been involved in organization of the Hampton University Graduate Studies (HUGS) summer school for graduate students in nuclear physics since 2002.

(v) **Collaborators and Other Affiliations**

(a) Close collaborators:

Jefferson Lab E94110 Collaboration (see above and supporting documents)

Jefferson Lab Hall C Spring '03 (Spring03) Collaboration (see supporting documents)

BONUS Collaboration (see supporting documents),

MINERvA Collaboration (see supporting documents)

(b) Graduate and Professional Advisors:

Mike Kovash (University of Kentucky), Tim Gorringe (University of Kentucky) Cynthia Keppel (Hampton University/JLAB), Rolf Ent (JLAB)

Steven A. Dytman
Curriculum Vitæ

A. Professional Preparation:

University of Rochester	Physics	B.S. 1971
Carnegie-Mellon University	Physics	M.S. 1973
Carnegie-Mellon University	Physics	Ph.D. 1978

B. Appointments: Professor, University of Pittsurgh, September, 1996

9/87 - 9/96 **Associate Professor**, University of Pittsburgh

9/82 - 9/87 **Assistant Professor**, University of Pittsburgh

9/79 - 9/82 **Sponsored Research Staff**, Massachusetts Institute of Technology

1/78 - 9/79 **Research Physicist**, Carnegie-Mellon University

9/71 - 1/78 **Research Assistant**, Carnegie-Mellon University

C. Representative Publications Related to Proposal (of about 80 in refereed journals):

1. "The $ep \to e'p(\eta)$ Reaction at and above the $S_{11}(1535)$ Baryon Resonance", R. Thompson, *et al.*, (CLAS Collaboration), Phys. Rev. Lett. **86,** 1702 (2001).

2. "Baryon Resonance Extraction from πN Data using a Unitary Multichannel Model", T.P. Vrana, S.A. Dytman, and T.-S. H. Lee,, Phys. Repts. **328,** 181 (2000).

3. *Physics and Instrumentation with 6-12 GeV Beams*, Proceedings of the Jefferson Lab Users' Group Workshop, S.A. Dytman, H. Fencker, and P. Roos, eds., Newport News, VA, June 15-18, 1998.

4. "The CLAS Drift Chamber System", M.D. Mestayer, *et al.*, Nucl. Instr. and Meth. **A449,** 81 (2000).

5. "CLEO-c and CESR-c: A New Frontier of Weak and Strong Interactions", R.A. Briere, *et al.*, (CLEO-c collaboration), report CLNS 01/1742, http://www.snowmass2001.org/Working_Group_E2/.

Selected Additional Publications

1. "Key Issues in Hadronic Physics", Simon Capstick, Steven Dytman, Roy Holt, Xiangdong Ji, John Negele, Eric Swanson, *et al.*, hep-ph/0012238.

2. "A Review of Coupled Channel Analyses for Extraction of Baryon Resonance Parameters", S. A. Dytman, HADRON2001, 9th International Conference on Hadron Spectroscopy, Protvino, Russia, AIP Conf. Proc. **619**, 287 (2002).

3. *Proceedings, NSTAR2002, Workshop on the Physics of Excited Nucleons*, Pittsburgh, Pennsylvania, S.A. Dytman, E.S. Swanson, eds., World Scientific, 2003.

4. "Model Dependence of the Properties of the S_{11} Baryon Resonances", Alvin Kiswandhi, Simon Capstick, and Steven Dytman,, Phys. Rev. C **69,** 025205 (2003).

5. "Kinematically Complete Measurement of $pp \to pn\pi^+$ Near Threshold", J.G. Hardie, S.A. Dytman, W.W. Daehnick, W.K. Brooks, R.W. Flammang, L. Bland, W.W. Jacobs, P.V. Pancella, T. Rinckel, J.D. Brown, and E. Jacobsen, Phys. Rev. C **56,** 20 (1997).

D. Synergistic and other Professional Activities:

2002 - 2004 Chairman, CLEO Spectroscopy Physics Working Group.

2001 Workshop Co-organizer - NSTAR2002, Physics of Excited Nucleons

1999 - 2001 Chairman, Baryon Resonance Analysis Group.

1997 - 1999 Jefferson Lab Users Group Board of Directors.

1997 - 1999 Chairman, CLAS Collaboration Coordination Committee.

1994 - 1997 Coordinator, CEBAF Large Acceptance Spectrometer (CLAS) Structure of the Nucleon physics working group.

1998 Workshop Co-organizer - Jefferson Lab Physics and Instrumentation with 8 GeV Beams and Beyond.

1990 - 1992 President, Vice-President, Bates Linear Accelerator Users' Group.

E. Collaborators over the last 48 Months:

All members of the MINERvA collaboration
All members of the CLAS collaboration
All members of the CLEO collaboration
T.-S. H. Lee, S. Capstick, C. Bennhold, M. Manley.

Post Graduate Advisors: Prof. Peter Barnes and Robert Eisenstein, Carnegie Mellon University; Prof. Aron Bernstein, MIT

Thesis Advisor: Prof. Robert Eisenstein, Carnegie Mellon

Previous PhD Students:

J. Hardie, T. Vrana, R. Thompson.

Previous Postdoctoral Scholars:

D. Asner, S. Mehrabyan, K. Y. Kim, D. Tedeschi, W. Brooks, M. Yamazaki, K. von Reden.

Biographical Sketch of Richard W. Gran

A. Professional Preparation

Carleton College, Physics and Music	B.A.	1994
University of Minnesota, Physics	Ph.D.	2002
University of Washington, Physics	Postdoctoral Associate	2002-2005

B. Appointments

Assistant Professor of Physics, Univ. of Minnesota Duluth, 2005-present
Research Associate, Univ. of Washington, 2002-2005
JSPS Fellow, KEK Accelerator Laboratory, 2003
Visiting Instructor, Carleton College, 1999-2000

C. Selected Publications

1. M. Hasegawa, et al., Search for coherent charged pion production in neutrino-carbon interactions, Phys. Rev. Lett., Observation of muon neutrino oscillation with an accelerator-based experiment, Phys. Rev. Lett. 95(2005) 252301.
2. E. Aliu, et al., Observation of muon neutrino oscillation with an accelerator-based experiment, Phys. Rev. Lett. 94 (2005) 081802.
3. R. Gran, Charged current events in the K2K near detectors, Nucl Phys. B (Proc. Sup.), 139 (2005) 54.

D. Synergistic Activities

1. Advisory committee for The FUNdamentals Center for Science, Technology, Engineering, and Math – YMCA of Duluth
2. Work with QuarkNet on the design of the muon telescope DAQ and related web portal, used by high school and undergraduate classes.
3. Assist with public tours of the Soudan underground research laboratory.

E. Collaborators and Other Affiliations

Collaborators:

Members of the MINERvA Collaboration
Members of the MINOS Collaboration
Members of the K2K Collaboration
Members of the Super-K collaboration
Members of the JLAB E04-001 Collaboration

PI's Graduate and Postdoctoral Advisors:

Prof. Keith Ruddick, University of Minnesota
Dr. R. Jeffrey Wilkes, University of Washington,
Dr. Makoto Sakuda, Okayama University, Japan.

Graduate and Postdoctoral Advisees: None.

Biographical Sketch
Cynthia E. Keppel

A. Professional Preparation

The American University, Washington, DC Physics Ph.D. (1995)
Inclusive Nucleon Resonance Electroproduction
At High Momentum Transfer
The American University, Washington, DC Physics M.Sc. (1991)
St. John's College, Annapolis, MD Liberal Arts B.A. (1984)

B. Appointments

Director, HU Nuclear and High Energy Physics Research Center – 1999-2001:
Professor, Hampton University (HU) University Endowed Professor – Fall 1995 - present:
Jefferson Lab Staff Scientist – Fall 1995 - present:
Co-Director, HU / EVMS Medical Physics Program – Fall 2002 - present:

Selected Honors

2000 State Council on Higher Education for Virginia Outstanding Faculty Award; 1996 -2001 National Science Foundation Faculty Early Career Development (CAREER) Award (5 year grant); 1999 SURA Thesis Prize Competition Winner, I. Niculescu (graduate student); U.S. patent 6389098, *Dual Mode Stereotactic Localization Method and Application*; 1999 Blake Lilly Prize (as mentor); Jefferson Lab User Group Board of Directors (current); American Physical Society (APS) Division of Nuclear Physics (DNP) Program Committee (current); Chair APS Southeastern Section George B. Pegram Award Committee (current); NIH National Advisory Research Resources Council (current); Hampton Roads Research Partnership Board of Directors (current); HU All Campus Honors Banquet Honoree (2006); APS DNP Executive Committee Nominee (current); (Co) Vice Chair APS Committee on the Status of Women in Physics (APS CSWP, 2002); Chair, APS CSWP Site Visit Chair (2001-2003); APS Committee on Minorities Member (2000)

C. Selected Relevant Publications (from 142)

Please note that many of these papers have long author lists, rendering it practical only to note the first author (who is traditionally the thesis graduate student on the experiment).

1. I. Niculescu, et al. *Experimental Verification of Quark-Hadron Duality*, Phys. Rev. Lett. 85, 1186 (2000), SPIRES top cite
2. I. Niculescu, et al. *Evidence for Valence Quark-Hadron Duality*, Phys. Rev. Lett. 85, 1182 (2000), SPIRES top cite
3. W. Melnitchouk, R. Ent, and C. Keppel *Parton-Hadron Duality*, Physics Reports, 406, 127-301 (2005)
4. V. Tvaskis, J. Arrington, M. E. Christy, R. Ent, C.E. Keppel, Y. Liang and G. Vittorini, *Experimental Constraints on Non-Linearities Induced by Two-Photon Effects in Elastic and Inelastic Rosenbluth Separations*, nucl-ex/0511021, accepted to Phys. Rev. C (2006)
5. R. Ent, C.E. Keppel, and I. Niculescu *Nucleon Elastic Form Factors and Local Duality*, Phys. Rev. D 62, 073008 (2000)

Selected Additional Publications

1. S. Liuti, R. Ent, C.E. Keppel, and I. Niculescu *Perturbative QCD Analysis of Local Duality in a Fixed W^2 Framework*, Phys. Rev. Lett. 89, 162001 (2002)
2. I. Niculescu, C. Keppel, S. Liuti, and G. Niculescu *Extraction of Higher Twists from Electron-Proton Inclusive Data at Large Bjorken x*, Phys. Rev. D 60, 094001 (1999)
3. J. Arrington, et al. *x- and ξ-scaling of the Nuclear Structure Function at Large x*, Phys. Rev. C 64, 014602 (2001)
4. M.E. Christy, et al. *Measurements of Electron Proton Elastic Cross Sections for $0.4 < Q^2 < 5.5$ GeV^2*, Phys. Rev. C **70**, 015206 (2004)

D. Synergistic Activities

1. Member of 25 approved experiments at the Thomas Jefferson National Accelerator Facility, 16 of which have been completed, Spokesperson of 9.

2. Member of The Coordinated Theoretical-Experimental Project on QCD (CTEQ), a multi-institutional collaboration devoted to a broad program of research projects and cooperative enterprises in high-energy physics centered on Quantum Chromodynamics (QCD) and its implications in all areas of the Standard Model and beyond.

3. Director, Hampton University Graduate Studies (HUGS) at Jefferson Lab Summer School (2002 - current).

4. Lead campus effort to develop novel nuclear medicine and radiotherapy instrumentation center.

E. Collaborators, Advisors, Students, Postdoctoral Researchers

Recent Close Collaborators:

John Arrington (ANL), Henk Blok (NIKHEF), Peter Bosted (JLab), Antje Bruell (JLab), Rolf Ent (JLab), Howard Fenker (JLab), Keith Griffeon (WandM), Sebastian Kuhn (ODU), Wally Melnitchouk (JLab), JLab Hall B BONUS experiment, FNAL MINERvA experiment, and JLab Hall C experiments E94-110, E99-118, E02-109, E04-001, collaboration listings in appendix.

Graduate and Professional Advisors:

Ray Arnold (UMass/SLAC), Peter Bosted (UMass/JLab), Warren Buck (UWash), Roger Carlini (JLab), Steve Rock (UMass), Zen Szalata (SLAC)

Supervised Postdoctoral Researchers:

Ketevi Assamagan (Brookhaven), M. Eric Christy (HU), Paul Gueye (HU), Vahagn Nazaryan (HU), Vladas Tvaskis (HU)

Graduated Doctoral Students:

Steven Avery (UPenn), Romuald David (industry), Yongguang Liang (Ohio), Ioana Niculescu (JMU)

Biographical Sketch of Donna Naples

A. Professional Preparation:

Sc.B. University of Pittsburgh, Field: Physics June, 1985.
Ph.D. University of Maryland, Field: Physics May, 1993.
Postdoctoral Fermi National Accelerator Lab, 1993-1995.

B. Appointments:

University of Pittsburgh, Associate Professor of Physics, 2004 – present.
University of Pittsburgh, Assistant Professor of Physics, 1998 – 2004.
Kansas State University, Assistant Professor of Physics, 1995 – 1998.
Research Associate, Fermilab, 1993 – 1995.

Fellowships and Honors:

DOE Outstanding Junior Investigator Award, 1996.
SURA CEBAF Research Fellowship Award 1990-91

C. Selected Publications

1. "Precision Measurement of Neutrino and Anti-neutrino Differential Cross Sections" M. Tzanov, D. Naples, *et al.*, *submitted to PRD*, HEP-ex/0509010, Sept 2005.
2. "Ionization Chambers for Monitoring of High-Rate Neutrino Beams", J. McDonald, *et al.*, Nucl. Instr. and Meth. A496, 293 (2003).
3. "A Search for $\nu_\mu(\overline{\nu}_\mu) \rightarrow \nu_e(\overline{\nu}_e)$ Oscillations at NuTeV, S. Avvakumov *et al.*, Phys. Rev. Lett. 89, 011804 (2002).
4. "A Precise Determination of Electroweak Parameters in Neutrino Nucleon Scattering.", G. P. Zeller, K. S. McFarland, *et al.*, Phys. Rev. Lett. 88, 091802 (2002).
5. "A High Statistics Search for $\nu_e \rightarrow \nu_\tau$ Oscillations., D. Naples *et al.*, Phys. Rev. D.59 Rapid Comm., 031101-1 (1999).

D. Synergistic Activities

1. Mentor, Pitt REU-FOM program, summer 1998-present
2. Participant, QuarkNet 2000-2005.
3. APS Division of Particles and Fields Executive Committee, (1998-2000).
4. Mentor, Minority summer student program, summer 1994,1997,1998
5. Mentor, Fermilab TRAC teachers program, summer 1994.
6. Mentor, DOE summer student program, summer 1994.

E. Collaborators and Other Affiliations:

(i) Collaborators

1. Braidwood Collaboration
2. Minerva Collaboration
3. Minos Collaboration
4. NuTeV Collaboration

(ii) PI's Graduate and Postdoctoral Advisors:

1. C. C. Chang and H. Holmgren, University of Maryland.
2. Robert Bernstein, Jeff Appel, Fermilab.

(iii) Advisees: graduate students (4) and postdoctoral scholars (4).

1. Graduate students: Ms. Debdatta Bhattacharya (2003-present), Ms. Voica Radescu (2000-present), Mr. Martin Tzanov (1999-2005), Dr. Andrew Alton (Kansas State University 1996-1998).
2. Postdocs: Dr. M. S. Kim (2005-present), Dr. Steven Boyd (2002-2004), Dr. Jeffrey McDonald (1998-2003), Dr. David Woods (Kansas State University 1996-1998).

BIOGRAPHICAL SKETCH: Jeffrey K. Nelson

(I) Professional Preparation

Education

University of Minnesota - Twin Cities	Physics	B.S. 1987
University of Minnesota - Twin Cities	Physics	Ph.D. 1994

Postdoctoral Research

University of Minnesota - Twin Cities	Experimental High Energy Physics	1994-1999

(II) Appointments

Assistant Professor, Physics Department, College of William & Mary, VA	2004-Current
Adjunct Assistant Professor, University of Minnesota - Twin Cities, MN	2001-2004
Applications Physicist, Particle Physics Division, Fermilab, IL	2001-2003
Senior Research Associate, University of Minnesota – Twin Cities, MN	1999-2001
Visiting Assistant Professor, University of St. Thomas, St. Paul, MN	1997-1998

(III) Publications

Selected Related Publications

"Neutrino Oscillation Effects in Soudan-2 Upward-Stopping Muons," W. Allison, G. Alner, D. Ayres, G. Barr, W. Barrett, P. Border, J. Cobb, D. Cockerill, H. Courant, D. Demuth, T. Fields, H. Gallagher, M. Goodman, T. Kafka, S. Kasahara, P. Litchfield, W. Mann, M. Marshak, W. Miller, L. Mualem, J. Nelson, A. Napier, W. Oliver, G. Pearce, E. Peterson, D. Petyt, K. Ruddick, M. Sanchez, J. Schneps, A. Sousa, J. Thron, N. West, Phys. Rev. **D** 72, 052005 (2005)..

"Spontaneous Light Emission from Fibers in MINOS," S. Avvakumov, W. Barrett, T. Belias, C. Bower, A. Erwin, M. Kordosky, K. Lang, R. Lee, J. Liu, W. Miller, L. Mualem, R. Nichol, J. Nelson, G. Pearce, M. Proga, B. Rebel, K. Ruddick, C. Smith, J. Thomas, P. Vahle, R. Webb, Nucl. Inst. & Meth. **A** 545, 2005.

"On the Linearity of the MINOS Light-Injection Calibration System," P. Adamson, L. Barrett, A. Belias, A. Blake, A. Cabrera, E. Falk, P.G. Harris, J. Hartnell, C. Howcroft, M. Kordosky, K. Lang, R. Lee, J. Liu, D. Michael, R. Morse, J.K. Nelson, R. Nichol, G. Pearce, K. Ruddick, P.N. Smith, P.A. Symes, J. Thomas, P.L. Vahle, R. Webb, A. Weber, R.F. White, Nucl. Inst. & Meth. **A** 521, 361-366, 2004.

"Measurement of the L/E Distribution of Atmospheric Neutrinos in Soudan 2 and Their Interpretation as Neutrino Oscillations," W. Allison, G. Alner, D. Ayres, W. Barrett, P. Border, J. Cobb, D. Cockerill, H. Courant, D. Demuth, T. Fields, H. Gallagher, M. Goodman, T. Joffe-Minor, T. Kafka, S. Kasahara, P. Litchfield, W. Mann, M. Marshak, R. Milburn, W. Miller, L. Mualem, J. Nelson, A. Napier, W. Oliver, G. Pearce, E. Peterson, D. Petyt, K. Ruddick, J. Schneps, A. Sousa, B. Speakman, J. Thron, N. West, Phys. Rev. **D** 68, 112005, 2003.

"A Large Liquid Scintillator Detector for a Long Baseline Neutrino Oscillation Experiment," P. Border, P. Cushman, Kenneth J. Heller, D. Maxam, J. Nelson, K. Ruddick, R. Rusack, R. Schwienhorst, T. Berg, T. Chase, M. Hansen, C. Bower, R. Hatcher, R. Heinz, L. Miller, S. Mufson, Nucl. Inst. & Meth. **A** 463 194-204, 2001.

Other Publications

"Measurements of the B Semileptonic Branching Fraction with Lepton Tags," CLEO Collaboration, Phys. Rev. Lett. 76: 1570-1574 (1996).

"Measurement of Charmless Semileptonic Decays of B Mesons," CLEO Collaboration, Phys. Rev. Lett. 71, 4111-4115 (1993).

"Observation of B-Meson Semileptonic Decays to Noncharmed Final States," CLEO Collaboration, Phys. Rev. Lett. 64, 16-20 (1990).

(IV) Synergistic Activities

- Co-PI for the W&M Physics REU/RET site grant. Coordinating the W&M Research Experiences for Teachers Site. Participated in establishing Underground Science Tours at the Soudan Underground Laboratory, which is located in the Soudan Underground Mine State Park and is operated by the Minnesota Department of Natural Resources (DNR). Over 4,000 science visitors have taken these tours each year. Participated in developing a multi-institutional summer teacher residency program. The PI helped produce display materials, train seasonal DNR guides, gave tours, and staffed daily Ask-a-Scientist Sessions at the Soudan Mine for the last four summers. A W&M RET sponsored high-school physics teacher participated in the program for the first time in 2005.
- Early proponent of scintillator-based, long-baseline experiments for neutrino factories and super beam experiments (e.g. six talks at the New Initiatives in the NuMI Neutrino Beam and NuMI Off-Axis Workshops). Member of the Technology Steering Committee for the NOvA Experiment. Member of various working groups (e.g. Working Group on Future Fermilab Neutrino Experiments with Upgraded Conventional Beams, Working Group on Future Neutrino Experiments at Fermilab, the APS Study of Future Neutrino Experiments, Detector Working Group of the International Scoping Study for a Neutrino Factory and Super Beam Facility).
- 2003 Comstock Lecturer at Minnesota State University-Moorhead, in rural western Minnesota. Gave a public seminar ("The Physics Underground: Studies of the Cosmos from a Half Mile Underground") and lectured to the local SPS chapter and astronomy courses.
- Elected Officer for the Minnesota Area Section of the American Association of Physics Teachers (MAAPT) for six years, maintained web site, and hosted the fall 2001 AAPT Section Meeting.
- Developing an electronics and instrumentation course including a 100 page text and associated laboratory manual at W&M. Restructuring the course to increase emphasis on PC interfacing, digital data collection, and computational data analysis using tools in common practice in physics and engineering. Developed new laboratories and an activity-based curriculum for music performance majors based on computer-aided collection and analysis of acoustical data for the University of St. Thomas. The course was taught jointly with the chair of the Music Department.

(V) Collaborators & Other Affiliations

(a) Collaborators and Co-Editors

Author lists for high energy physics collaborations often number over 200 researchers and are much too long for a two-page biographical sketch, therefore web links are provided.

- MINOS Collaboration (see http://www-numi.fnal.gov/collab/collab.ps)
- MINERvA Collaboration (see http://minerva.fnal.gov/collab.html)
- NOvA Collaboration (see the author list of http://arxiv.org/abs/hep-ex/0503053)
- Soudan 2 Collaboration (see the author list of http://arxiv.org/abs/hep-ex/0507068)

(b) Graduate and Post-doctoral Advisors

- Graduate Advisor: Ronald A. Poling (Univ. of Minnesota);
- Postdoctoral Advisors: Roger Rusack (Univ. of Minnesota); Keith Ruddick (Univ. of Minnesota).

(c) Thesis Advisor and Postgraduate-Scholar Sponsor

- Thesis Students: Steven Coleman, Aiyana Garcia, Rita Schneider.
- Postdoctoral Scholars: Francisco X. Yumiceva.

Biographical Sketch of Vittorio Paolone

A. Education:

Sc.B. California State University, Northridge, California, 1981. Field: Physics

M. A. University of California, Davis, California, 1982. Field: Physics

Ph.D. University of California, Davis, California, 1990. Field: Physics

B. Appointments:

University of Pittsburgh, Associate Professor of Physics, September 2002 – Present.

University of Pittsburgh, Assistant Professor of Physics, January 1997 – September 2002.

University of California, Davis, Staff Research Physicist, 1993 –1996.

University of California, Davis, Reserach Associate, 1990 –1993.

Fellowships and Honors:

University of Pittsburgh: Chancellors Distinguished Research Award, 2001.

Department of Energy: Outstanding Junior Investigator Award, 1997.

John W. Nagle Outstanding Senior Award (Undergraduate/Physics), 1981.

C. Publications

Publications relevant to proposed research

1. **MINERνA Collaboration**, *MINERνA: High statistics neutrino scattering using a fine-grained detector.* Int. J. Mod. Phys. A **20**, 3078 (2005)

2. **MINERνA Collaboration**, *Neutrino scattering uncertainties and their role in long baseline oscillation experiments.* arXiv:hep-ex/0410005 (2004)

3. **G. Bonvicini, D. Naples, V. Paolone**, *Review of the Technical Issues Associated with the Construction of a Solar Neutrino TPC*, Nucl. Instr. and Meth. A**491**, 402 (2002).

4. **Fermilab DONUT Collaboration (K. Kodama** *et al.*), *Observation of Tau Neutrino Interactions.* Fermilab-Pub-00-335-E, Phys. Lett. B **504**, 218 (2001)

Other Significant Publications

1. **B. Lundberg, K. Niwa, V. Paolone**, *Observation of the Tau Neutrino.* Annu. Rev. Nucl. Part. Sci. **53**, 199 (2003)

2. **Vittorio Paolone**, *Status of the MINOS Experiment.* Prepared for Europhysics Neutrino Oscillation Workshop(NOW2000), Conca Specchiulla, Otranto, Lecce, Italy, Sept. 2000, Nucl. Phys. Proc. Suppl. **100**, 197 (2001)
3. **Fermilab E653 Collaboration (K. Kodama** *et al.***)**, *Measurement of* $B(D_S^+ \to \mu^+\nu)/B(D_S^+ \to \phi\mu^+\nu))$ *and Determination of the Decay Constant* f_{D_S}. DPNU-96-33(hep-ex/9606017), Phys. Lett. B **382**, 299 (1996).

D. Synergistic Activities

1. Mentor(Nichelle Madison), Pitt REU-FOM program, summer 2005

E. Collaborators and Other Affiliations:
(i) Collaborators

1. Member of the ATLAS Collaboration at CERN (2000 physicists)
2. Member of the Minos Collaboration at Fermilab (150 physicists)
3. Spokesperson for the the DONUT Collaboration at Fermilab (30 physicists)
4. Member of the Cosmos Collaboration at Fermilab (50 physicists)
5. Member of the E687 Collaboration at Fermilab (50 physicists)
6. Member of the E653 Collaboration at Fermilab (50 physicists)

(ii) PI's Graduate and Postdoctoral Advisors:

1. Phil Yager, University of Californis, Davis

(iii) Advisees: graduate students (3) and postdoctoral scholars (3), for last five years.

1. Dr. Chaouki Boulahouache, Dr. Steven Boyd, Dr. Jeffrey McDonald, University of Pittsburgh
2. Ms. Shanti Wendler, Mr. Ben Brown, Mr. Barun Dhar, University of Pittsburgh.

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Rochester

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Kevin S McFarland

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Kevin S McFarland - Professor**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Arie Bodek - Professor**	**0.00**	**0.00**	**0.00**	**0**	
3. **Howard Budd - Senior Scientist**	**0.00**	**0.00**	**0.00**	**0**	
4. **Steven L Manly - Associate Professor**	**0.00**	**0.00**	**0.00**	**0**	
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**4**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**1**) GRADUATE STUDENTS				**5,250**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**5,250**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**0**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**5,250**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
Cryogenic Target Stand $ **7,500**					
Education & Public Outreach Matls/Design/Labor **16,260**					
Module Response Mapper **81,550**					
Others (See Budget Comments Page…) **226,906**					
TOTAL EQUIPMENT				**332,216**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **13,673**					
2. TRAVEL **0**					
3. SUBSISTENCE **1,500**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**15,173**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**405,802**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**405,802**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**758,441**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **Off-campus MTDC (Rate: 28.9000, Base: 5250) (Cont. on Comments Page)**					
TOTAL INDIRECT COSTS (F&A)				**31,534**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**789,975**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **789,975**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Kevin S McFarland

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

**** D- Equipment**
Solid Nuclear Targets (Amount: $ 46254)
Testbeam Detector Component (Amount: $ 61589)
Testbeam Detector Stand (Amount: $ 119063)
**** I- Indirect Costs**
Subcontracts, first $25,000 of 4 (Rate: 28.9000, Base 99972)
Undergraduate participant stipend (Rate: 25.0000, Base 4500)

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **University of Rochester**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Kevin S McFarland**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Kevin S McFarland - Professor**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Arie Bodek - Professor**	**0.00**	**0.00**	**0.00**	**0**	
3. **Howard Budd - Senior Scientist**	**0.00**	**0.00**	**0.00**	**0**	
4. **Steven L Manly - Associate Professor**	**0.00**	**0.00**	**0.00**	**0**	
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**4**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**1**) GRADUATE STUDENTS				**5,250**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**5,250**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**0**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**5,250**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ **332,216**					
TOTAL EQUIPMENT				**332,216**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **13,673**					
2. TRAVEL **0**					
3. SUBSISTENCE **1,500**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**15,173**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**405,802**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**405,802**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**758,441**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**31,534**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**789,975**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **789,975**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **Kevin S McFarland**

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

PI: Kevin S. McFarland **Institution: University of Rochester**

Budget Justification Overview
This document details the costs requested for the proposal project. The costs cover primarily equipment, materials and supplies, and labor. M&S and Labor for work on MINERvA at Rochester are budgeted through the S.W. Barnes Laboratory, a fully-costed shop, and therefore appear as "Equipment" items and carry no indirect costs. Costs are based on vendor estimates if applicable and on experience for similar construction projects conducted by the PIs.

Salary, Wages, and Benefits: ***$5,250***

SENIOR PERSONNEL: No salaries for Senior Personnel requested.

OTHER PERSONNEL: We request 3 summer months of support for a graduate student to work with the student/teacher team (see Participant Costs) on the "mini-MINERvA" education and outreach project. Per University of Rochester policy, no fringe benefits are requested for students.

Equipment: ***$332,215***

Equipment for MINERvA Construction: ***$315,955***

Rochester has primary responsibility for materials and labor for installation of the solid nuclear targets, design and construction of the cryogenic target stand, construction of the module response mapper, purchase of materials for the MINERvA testbeam modules, and construction of the testbeam detector box and stand.

Much of the Rochester work will be carried out on site at FNAL, often in collaboration with FNAL technicians. Labor costs requested here are for Rochester-employed technicians and engineers only; collaborating FNAL engineering and technical staff are paid for directly by FNAL and are not part of the proposal. Members of the FNAL technical staff, technician time for scintillator production and fiber mirroring and polishing, welding needed for the assembly of the nuclear target plans and safety oversight. FNAL has agreed to these items as detailed in the supporting documentation regarding the FNAL commitment. The scintillator extrusions and prepared WLS fibers will be shipped to the College of William and Mary for scintillator plane fabrication as detailed in its budget request. Design work on the cryogenic target stand will be closely coordinated with the Hampton University technical staff responsible for the vessel. Design work on the testbeam detector box will be coordinated with Minnesota-Duluth personnel responsible for the operation plan. Design work for the module response mapper and nuclear targets will be complete by the start of the proposed work.

Budget categories shown on the equipment budget page are repeated below with corresponding subcategories shown in italics.

Solid Nuclear Targets	$46,254
Target Plates (Pb, steel, graphite)	*$37,042*
Target Support Frames and Fixtures	*$ 7,095*
Target Assembly Labor	*$ 2,117*

The Pb and Steel target plates and steel target frame pieces will be purchased pre-cut and encapsulated in acrylic paint directly from the same vendors supplying calorimetric absorbers to MINERvA and shipped to Fermilab for assembly. The graphite plates will also be pre-cut and shipped to FNAL. FNAL welders, not supported by this task, will assemble the support frames. Rochester technicians will install target support fixtures to the frame and install the target planes.

Cryogenic Target Stand	$7,500
Design of Target Stand	*$1,320*

Machining and Assembly Labor	*$5,280*
Target Stand Materials	*$ 900*

The cryogenic target vessel with an anticipated total mass of <350 kg must be supported approximately 2.5 meters above the floor of the detector hall in order to be centered on the MINERvA detector. The current concept calls for a support structure mounted off of the rails of the planned detector support stand. Costs requested for this item includes design, machining of parts, assembly of support stand (mechanical engineer, machinist and technicians from S.W. Barnes lab), and materials. Installation in the hall will be completed by FNAL personnel.

Module Response Mapper	$81,550
Assembly Labor	*$46,134*
Materials	*$16,738*
Commissioning Labor	*$18,678*

The module response mapper is a double-headed source mover system that is built to be placed over a MINERvA detector module on its assembly strongback. Design of the mapper will be completed from R&D funds for the MINERvA project. Requested funds here support the materials and labor (technicians from the S.W. Barnes lab) to assemble and commission the module. A prototype module will be available for mapper commissioning in December 2006.

Testbeam Detector Components	$61,589
Scintillator Materials and Shipping	*$ 6,240*
WLS Fiber and Shipping	*$20,400*
Absorber Plates	*$34,949*

Testbeam Detector Box and Stand	$119,063
Design	*$18,563*
Stand/Box Fabrication	*$40,320*
Box/Stand Materials	*$30,000*
Installation and Commissioning	*$30,180*

Scintillator bars for the MINERvA testbeam detector will be extruded at the NICADD/FNAL continuous in-line extrusion facility at Fermilab. These extrusions are identical to the MINERvA inner detector and are made from polystyrene, doped with PPO and POPOP, and are triangular in cross-section (3.3x1.7cm) with a hole for the WLS fiber in the middle. Increased light collection is ensured by a thin (0.3mm) co-extruded coating of TiO2 loaded polystyrene on the outside. Materials for production, including Styron 663, dopants and TiO2 will be purchased by University of Rochester. Labor will be provided by Fermilab under the support agreement.

The WLS fiber will be Kuraray 1.2mm S-35 J-type fiber, purchased on spools and shipped to FNAL. Nearly the entire cost of this sub-project can be attributed to the fiber purchase from Kuraray. Qualification and testing (sampling one per batch) of spools will be done by University of Rochester graduate students and physicists (not supported by this proposal) using existing test fixtures. FNAL technicians (not supported in this proposal) will cut the fiber to length and add mirrors at the vacuum deposition facility at Lab 8. Rochester technicians will pack the fibers for shipping to the scintillator module factories at Hampton and William and Mary.

Absorber plates will be purchased pre-cut and encapsulated in acrylic paint directly from vendors and shipped to Fermilab for assembly.

The testbeam detector will be housed in a light tight box with readout PMT boxes half inside and half outside the dark volume (as with the current MINERvA vertical slice test). The box will

include internal support structures for the scintillator planes and absorber planes. The support structures will be moveable to allow for reconfiguration of the active detector planes and absorbers to simulate different parts of the MINERvA detector. This proposal will support the design and fabrication of all parts for the box (S.W. Barnes lab mechanical engineer, machinist and technicians), as well as the installation of the completed detector planes and purchased absorbers into the box in the testbeam hall.

Education and Public Outreach: ***$16,260***

Materials, Design and Shop Labor for 'Mini-MINERvA'	$16,260
CCD Camera	*$3,400*
Image Intensifier	*$5,400*
Mini-MINERvA Dark Box Materials	*$6,000*
Mini-MINERvA Dark Box EDIA	*$ 600*
Shop Labor: Mini-MINERvA Dark Boxes	*$ 860*

Equipment is requested for the Mini-MINERvA detectors as detailed in the project description. Nominal shop labor and design charges are requested for student training and parts design. Labor to construct Mini-MINERvA and the dark boxes for the mobile Mini-MINERvA is described under Participant Costs.

Participant Costs for MINERvA Educational Public Outreach ***$15,173***

Associated with the construction of the MINERvA detector, we plan a strong program of related education and outreach activities. These activities are budgeted under participant costs consistent with the NSF-supported PARTICLE program and with undergraduate activities at the University of Rochester. We seek funds for a team of undergraduates, high school students and a teacher to construct a mini-MINERvA detector and mobile mini-MINERvA dark boxes. We request $13,673 in stipends to support two summer undergraduates (10 weeks, $4500 as part of the Research Experience for Undergraduates program), one high school teacher (6 weeks), and two high school students (6 weeks; supervised by the teacher) at University of Rochester. We also request modest housing and meal subsistence costs of $1,500 for the undergraduates.

Sub-Contracts: ***$405,802***

The University of Rochester will sub-contract assembly of the planes of scintillator to William and Mary, design and construction of the cryogenic target to Hampton University, construction of the light injection system to Pittsburgh and operation of the testbeam detector to Minnesota-Duluth. Their costs are detailed on separate budget pages and justifications.

Hampton University	$192,596
University of Minnesota-Duluth	$ 24,972
University of Pittsburgh	$119,692
The College of William and Mary	$ 68,542

F&A (Indirect) Costs: ***$31,534***

F&A (indirect) costs are requested for the graduate student at the off-campus rate of 28.9% MTDC. The first $25,000 of each sub-contract for the total project is subject to the same off-campus indirect rate. Finally, the stipends of the undergraduates described under participant costs are subject to a special rate of 25%. Costs exempt from F&A in this proposal include all equipment and charges from the University's fully costed service centers including the Sidney W. Barnes Research Laboratory (Physics shop).

Total Costs Requested from NSF: **$789,975**

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **College of William and Mary**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Jeffrey W Nelson**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Jeffrey W Nelson**	**0.00**	**0.00**	**0.00**	$ **0**	$
2.					
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**2**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**18,000**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**2**) UNDERGRADUATE STUDENTS				**7,200**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**25,200**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**8,291**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**33,491**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **detector planes** $ **13,500**					
TOTAL EQUIPMENT				**13,500**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**5,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**5,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**51,991**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **expenses less equipment (Rate: 43.0000, Base: 38491)**					
TOTAL INDIRECT COSTS (F&A)				**16,551**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**68,542**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **68,542**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **Jeffrey W Nelson**

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **College of William and Mary**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Jeffrey W Nelson**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Jeffrey W Nelson**	**0.00**	**0.00**	**0.00**	$ **0**	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**2**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**18,000**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**2**) UNDERGRADUATE STUDENTS				**7,200**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**25,200**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**8,291**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**33,491**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ **13,500**					
TOTAL EQUIPMENT				**13,500**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**5,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**5,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**51,991**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**16,551**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**68,542**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **68,542**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **Jeffrey W Nelson**

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

William & Mary Budget Justification

This budget covers the assembly of the test beam detector planes from components purchased and prepared by the Rochester group.

Personnel

The labor to produce each of these planes of materials is based on the Basis of Estimate documentation presented at the December, 2005 MINERvA preliminary CD 1 project review, which was based on the as-realized labor requirements for MINOS scintillator assembly. A total of 1800 hours of effort are anticipated for assembly of the test beam detector planes.

To meet these requirements, support for 900 hours of combined effort from two full-time MINERvA assembly technicians and 900 hours of undergraduate technician effort have been requested. The technician wage is $20/hr and fringe rate of 45% applies to these wages. The undergraduate wage is $8.00/hr and FICA (7.65%) is charged on undergraduate support.

Equipment

The assembly components are costed at $250 per plane for a total cost for the test beam detector of $13,500 including spare and waste. This aggregated test beam detector procurement qualifies to be declared as capitol equipment.

The required fixturing and assembly equipment will be available from MINERvA detector plane assembly production and directly applicable for the test beam detector plane assembly.

Other Expenses

$5,000 for shipping crates and shipping charges are requested.

Indirect Charges

Equipment is exempt from indirect costs. All other items are charged an ONR negotiated indirect rate of 43%.

SUMMARY PROPOSAL BUDGET YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **Hampton University**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **M. Eric Christy**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **M. Eric Christy**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Cynthia E Keppel**	**0.00**	**0.00**	**0.00**	**0**	
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**2**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**2**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**54,400**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**54,400**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**11,152**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**65,552**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **cryostat and control systems per justification** $ **110,000**					
TOTAL EQUIPMENT				**110,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**0**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**175,552**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **off campus rate on all but equip (Rate: 26.0000, Base: 65552)**					
TOTAL INDIRECT COSTS (F&A)				**17,044**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**192,596**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **192,596**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **M. Eric Christy**

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
Hampton University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
M. Eric Christy

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **M. Eric Christy**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Cynthia E Keppel**	**0.00**	**0.00**	**0.00**	**0**	
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**2**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**2**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**54,400**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**54,400**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**11,152**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**65,552**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ **110,000**					
TOTAL EQUIPMENT				**110,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**0**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**175,552**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**17,044**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**192,596**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **192,596**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME
M. Eric Christy

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

Hampton University
Budget Justification

The outfitting of helium cryotarget instrumentation and slow controls, and the development of relevant interfaces for same, will be undertaken at Hampton University (HU). Also, HU will assume responsibility for target and cryostat commissioning and leak and heat load testing, as well as the development of appropriate safety documentation and operating procedures. The latter will all be subject to technical and safety review by Fermilab.

The nuclear experimental group at HU has substantial experience in slow controls, in particular for target instrumentation. The HU group had this responsibility for the novel Jefferson Lab Hall B BONUS experiment target, which operated successfully in 2005. Additionally, the group was active in cryotarget development for the Jefferson Lab Hall C 200W hydrogen and deuterium targets in the days before a lab-wide target group was formed. Dr. Keppel is a listed Hall C target expert (see http://www.jlab.org/ smithg/target/Spring-03%20tgt/Slide5.JPG) and is responsible for periodic training in the use of these targets. The high power Hall C cryotargets have been in successful periodic use for nearly a decade.

1 A. Senior Personnel

The labor requirements for this project were estimated by the technical staff at Fermilab, based on prior experience. 28 engineering and technical man-weeks are estimated to be required for target and cryostat commissioning, leak and heat balance testing, safe use verification, and documentation. An additional 4 engineering and technical man-weeks are estimated to be required for instrumentation and control development and implementation. In total and without contingency, 32 man-weeks will be required for this project. At a rate of $1,700 per week average, this cost will be $54,400. We have assumed this to be one full time engineer on the budget page. However, a part time engineer combined with a part time technician, for instance, would be acceptable.

Our plan is to also enlist student help for control software development such as GUI interfaces, and to take testing data. No support is requested for these students, who would likely come from the HU NSF/REU program, UnIPhy (Undergraduate Institute in PHYsics), and from junior graduate students already supported by other means.

2 C. Fringe Benefits

Fringe benefits are calculated at a rate of 20.5%. Therefore, the total request here is $54,400 (senior personnel) x 1.205 = $11,152.

3 D. Equipment

The equipment requested to be purchased by HU totals $110,000, as follows. A similar cryocooler system was purchased by Fermilab for the Cryogenic Dark Matter Search (CDMS) experiment this past year, and the costs below are a direct extrapolation from the CDMS costs.

- cryostat 60,000;
- pressure instruments 5,000;
- level and flow instruments 5,000;
- controller 30,000;
- human machine interface 10,000;
  The cryostat cost estimate is from Sumitomo Cryogenics of America, Inc., 1500 C Higgins Road, Elk Grove Vilalge, Il 60007/

4. I. Indirect Costs

The Hampton University off campus Indirect Cost Rate is 26%, applied to everything other than equipment and student support. The total requested here, then, is $17,044.

SUMMARY PROPOSAL BUDGET YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Minnesota Duluth

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Richard Gran

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Richard Gran**	**0.00**	**0.00**	**0.00**	$ **0**	$
2.					
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**1**) GRADUATE STUDENTS				**4,160**	
4. (**2**) UNDERGRADUATE STUDENTS				**8,000**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**12,160**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**1,632**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**13,792**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**6,240**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**0**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**20,032**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **off campus (Rate: 26.0000, Base: 18999)**					
TOTAL INDIRECT COSTS (F&A)				**4,940**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**24,972**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **24,972**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Richard Gran

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **University of Minnesota Duluth**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Richard Gran**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Richard Gran**	**0.00**	**0.00**	**0.00**	$ **0**	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**1**) GRADUATE STUDENTS				**4,160**	
4. (**2**) UNDERGRADUATE STUDENTS				**8,000**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**12,160**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**1,632**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**13,792**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**6,240**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**0**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**20,032**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**4,940**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**24,972**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **24,972**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **Richard Gran**

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

Budget Justification

Institution: University of Minnesota, Duluth

Budget Justification Overview

This P.I. is responsible for the integration and operation of the many pieces of the beam test portion of this proposal. This includes organizing the setup and staging of the detector components, described elsewhere in this proposal, prior to exposure in the test beam. Also we are responsible the run plan, the test-beam shift schedule, checks of the data, and the first-pass analysis of the data. The shifts will be taken by a combination of personel within the collaboration and this proposal, including the three students indicated below.

We request funds for summer salary and travel for one Master's and two undergraduate students to participate in this beam test. The Master's student will play a major role in the first pass analysis of the data. The undergraduates will assist in the setup and take shifts running the beam test. If one of the undergraduates is suitably prepared, she/he will also play a significant role in the analysis of data.

Salary, Wages, and Benefits: ***$13,792***

SENIOR PERSONNEL: No salaries for Senior Personnel requested.
OTHER PERSONNEL:
One Master's student wages 10 weeks in summer = $4,160 x 24.8% fringe
Two undergraduate students 10 weeks wages 2 students x $4,000 x 7.5% fringe
(undergraduate rate is $10 per hour, 40 hours per week, 10 weeks)

Equipment: ***$0***

Travel: ***$6,240***

Travel funds are requested for three six-week trips to Fermilab (18 weeks) from Duluth, MN, for each of the three students. Fermilab Housing and $20 per diem are assumed for this duration, plus one round-trip in an automobile for each of the three students. The P.I. does not request travel funds from this proposal.

Indirect Costs: ***$4,940***

All indirect costs are at the off-campus rate of 26.0%, and are not applied to graduate student fringe rate, but are applied to all other budgeted items.

Total costs requested from NSF: ***$24,972***

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Pittsburgh

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Steven A Dytman

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Steven A Dytman**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Donna Naples**	**0.00**	**0.00**	**0.00**	**0**	
3. **Vittorio Paolone**	**0.00**	**0.00**	**0.00**	**0**	
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**1**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**20,800**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**2**) UNDERGRADUATE STUDENTS				**9,600**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**30,400**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**7,685**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**38,085**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
pulser box mainframe, components, optical fiber $ **30,800**					
TOTAL EQUIPMENT				**30,800**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**32,336**	
TOTAL OTHER DIRECT COSTS				**32,336**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**101,221**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
on personnel (Rate: 48.5000, Base: 38085)					
TOTAL INDIRECT COSTS (F&A)				**18,471**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**119,692**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **119,692**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Steven A Dytman

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Pittsburgh

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Steven A Dytman

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Steven A Dytman**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Donna Naples**	**0.00**	**0.00**	**0.00**	**0**	
3. **Vittorio Paolone**	**0.00**	**0.00**	**0.00**	**0**	
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**1**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**20,800**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**2**) UNDERGRADUATE STUDENTS				**9,600**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**30,400**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**7,685**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**38,085**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **$ 30,800**					
TOTAL EQUIPMENT				**30,800**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**32,336**	
TOTAL OTHER DIRECT COSTS				**32,336**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**101,221**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**18,471**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**119,692**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **119,692**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Steven A Dytman

ORG. REP. NAME*

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INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

Budget Explanation: Light Injection

The Light Injection (LI) system will be an important calibration tool. Since it is similar to what was used in the (much larger) MINOS system, we will start with their designs and adapt them to our situation. The costs come in 2 components, modification to the PMT boxes and the LED pulser box/PIN diode box pair which provides the light and monitors it. Costs are estimated from previous experience.

The light is injected into the PMT box, a light tight tube where the fibers are joined to the PMT. The modifications to this assembly involve a new connector and diffuser assembly, additional equipment and labor are allotted $10,000.

The pulser box takes the control signal from the MINERνA DAQ system, pulses a set of LED's, fans the light out, and optical fibers take the light to each PMT. This box has delicate machining for the optical fanouts and straightforward electronics to control the LED. The PIN diodes (a separate enclosure) are needed to monitor each LED output, particularly if the system is used to measure nonlinearity. The main costs include optical fiber ($10,000), electronics ($8,000), and a light-tight enclosure ($3,000). As they are part of a high cost piece of equipment, these components carry no overhead. Electrical and machine shops in the Department of Physics and Astronomy are subsidized and there is no overhead on these charges. About 75 days in the electronics shop ($28 per hour) and mechanical shop ($22 per hour) are anticipated. Both shops have design capabilities. Funds are also allocated for 3 undergraduate researchers and a technician to assemble and test the pieces.

PI: **Kevin S. McFarland**
Institution: **University of Rochester**

Facilities, Equipment & Other Resources

The University of Rochester is a private research and teaching university. The Department of Physics and Astronomy has a long and distinguished history of active research in both experimental and theoretical particle and nuclear physics, and has extensive involvement in leading contemporary experimental collaborations. The High Energy and Nuclear Physics groups are housed in close proximity and within the same building as the rest of the Department, encouraging interaction with colleagues with the same general interests and those skilled in related fields.

The Department's Sidney W. Barnes Research Laboratory (shop) offers extensive machining, electronics, and mechanical engineering support as well as design and drafting resources, to assist researchers with experiments, detector development and accelerator projects. The University's College maintains a large and varied machine shop in an adjacent building to complement the skills of the SWBRL.

Under the auspices of the SWBRL, the High Energy and Nuclear Physics groups share computing resources, including two full-time system managers employed by the Department. The group benefits from a shared video-conferencing facility suitable for communication with collaborators. Full-time administrative and secretarial support for the High Energy Physics and Nuclear Physics groups are provided, separate from resources in the Department.

The Department has an established research-based education and outreach programs involving teachers, undergraduates, and high school students. Funding by NSF and other sponsors for two REU site awards and other outreach programs, such as PARTICLE, help support these activities. The Department's commitment to outreach programs is critical to the success of the educational and public outreach component of this proposal.

The High Energy Physics group has an established relationship with Fermi National Accelerator Laboratory and has extensive experience (most recently, the CDF plug calorimeter upgrade and the CMS hadronic calorimeter) in building large-scale detectors on the FNAL site with Rochester personnel. We expect to continue to be able to take advantage of our contacts at Fermilab in this proposal to leverage space, engineering and computing resources for the final assembly of the MINERvA detector.

Facilities, Equipment, and Other Resources, Hampton University (HU)

Hampton University is an historically black college (HBCU) located on Virginia's tidewater peninsula, about 12 miles from the Thomas Jefferson National Accelerator Facility and about 8 miles from the NASA Langley Research Center. The HU Physics Department offers BSc, MSc, and PhD degrees in physics, with about 30 graduate students and 30 regular faculty in the department. According to American Institute of Physics statistics, HU graduates over half of the doctoral degrees in physics awarded to African-Americans annually. The department houses several research centers, including an NSF Physics Frontier Center for particle and nuclear physics research. Recently, the department's Center for Atmospheric Science facilitated HU becoming the first HBCU to be prime contractor for a NASA satellite mission.

Laboratory

The HU nuclear experimental suite consists of over 1,400 square feet of lab space with anelectronic lab station, mechanical lab station, computer/graphic processing bay and a dedicated radiation hot lab. The hot lab operation is licensed by both the State of Virginia and the Nuclear Regulatory Commission giving the group the ability to order and use various radioactive sources for detector testing. In addition to the direct facility resources, the group has excellent access to additional machine shops and electronics design labs at the nearby Jefferson Lab, where a partnership agreement is in place. The physics department, furthermore, has a 1,300 square foot class-10,000 clean room for component preparation and module construction.

Office

Dedicated office space for senior personnel, technical associates, and students is provided by Hampton University. Hampton University, additionally, will provide 25% of an administrative assistant (already working with the nuclear experimental group) for this project.

Computer

Current computing equipment utilized by the Hampton University experimental nuclear physics group consists of three Pentium IV and five dual Pentium III CPUs, individual PC workstations. These provide both desktop computers for faculty/staff/students, as well as data analysis workstations. Prices of each machine at the time of purchase was ~ $2000:00, including 20 inch monitor. Computing resources also include two 0.5 TB Fileservers providing local storage of raw experimental data, as well as data at various stages of analysis. In addition, the group maintains one workgroup laserjet printer (HP LaserJet 4000TN), and one color workgroup laserjet printer (HP Color LaserJet 4550N). Service contracts are maintained on all computing resources equipment.

The computing resources for this work are adequate currently, but are planned to be upgraded over the course of this project.

PI's: **Steven Dytman, Donna Naples, Vittorio Paolone**
Institution: **University of Pittsburgh**

Facilities, Equipment & Other Resources

The University of Pittsburgh is a public research and teaching university. The Department of Physics and Astronomy has a long and distinguished history of active research in both experimental and theoretical particle and nuclear physics, and has extensive involvement in leading contemporary experimental collaborations.

The Department maintains electronics and machine shops which primarily do jobs for scientists locally. The University provides some salary support to keep rates low. The skill level of these people is high and many quality jobs have been done successfully. A notable example is the Jefferson Lab drift chamber construction project led by Dytman. The Nuclear Physics Lab formerly held a van de Graaf accelerator. The lab was renovated and converted to modern research laboratories in the 1990's. All particle physics lab work is done in that building.

The High Energy group maintains computing resources for the large number of students and other researchers working at the University. The Department has a full-time technician who maintains these computers.

The Department has an established research-based education and outreach programs involving teachers, undergraduates, and high school students. A REU program with focus on minorities has successfully trained about a dozen students each summer for over a decade. Our group has a very strong record of training undergraduates in research; over 20 students worked with us in the last decade and 4 of them won the departmental undergraduate research award.

The High Energy Physics group has an established relationship with Fermi National Accelerator Laboratory, particularly CDF. Paul Shepard was co-manager of the CDF Run II silicon detector. Naples and Paolone have worked on various detector projects in neutrino experiments. Thus, the Light Injection project will naturally fit into the research program in our department.

PI: **Jeffrey K. Nelson**
Institution: **The College of William and Mary**

Facilities, Equipment & Other Resources

Although William and Mary is best known as a liberal arts institution, the physics department has offered Ph. D. degrees since the mid 1960s and awards approximately 10 such degrees per year. The Physics Department, with 28 active professors, also has a strong undergraduate program graduating roughly 20 physics majors each year.

William & Mary, the Jeffress Memorial Trust, and the Commonwealth's Higher Education Equipment Trust have funded a pilot computing facility based on ten dual-processor Linux PCs, a 4Tb disk server, additional PCs, a web server, gigabit networking to the campus backbone, associated storage and support hardware with application to the proposed research. The College will provide a 350 sq.ft. laboratory for hosting the computing hardware. The college provides all necessary infrastructure to deploy the farm including HVAC, power, network security, and network infrastructure in the form of a maintained direct fiber connection to the campus backbone router, and a planned 10GB connection to the National Lambda Rail.

The nuclear and particle physics group maintains an active set of laboratories for the construction and testing of detector systems for use in experiments at Fermilab, JLAB, and other facilities. Three laboratories have been allocated for the PI's research. They include a 750 sq.ft. laboratory with an adjoining 30 sq.ft. darkroom, freight doors, and 3t monorail access to the Small Laboratory loading dock and a second 750 sq.ft. laboratory both to be used for the detector construction proposed at W&M.

The Physics Department has ten active members in experimental nuclear and particle physics. We consider ourselves a collective research group, which provides significant support in the form of shared resources and intellectual support. In addition, William & Mary is 15 miles from JLAB and 20 miles from MINERvA collaborators at Hampton University.

The department maintains a fully equipped and staffed machine shop with CNC machining and in-house design capability. The shop's current rate is $20/hr. W&M will provide the administrative support required for the activities outlined in this proposal.

PI: **Richard Gran**
Institution: **University of Minnesota Duluth**

Facilities, Equipment & Other Resources

The University of Minnesota Duluth is a large branch campus of the public University of Minnesota system with an enrollment of 10,000 students. It offers undergraduate and Master's degrees in physics. The physics department has seven full-time faculty, including the experimental neutrino physics group which has two faculty members.

In recent years, students from physics, electrical and computer engineering, computer science, and science education have participated in research activities with the MINOS and Super-Kamiokande experiments, and also the SuperNova Early Warning System. The neutrino group's interests include fundamental interactions, neutrino oscillations, and neutrino astrophysics. A significant number of undergraduates and Master's students pursue a Ph.D. Following their work at UM Duluth. Due to its proximity, the group plays a significant role in the operation of the MINOS far detector, which is 1.5 hours drive from campus. We also maintain close ties to the large experimental HEP group at the Twin Cities campus.

The physics department has a small machine shop with one full-time staff member. The neutrino group maintains a collection of equipment and parts, including test generators, oscilloscopes, NIM and VME modules, and other data acquisition equipment suitable to prototype and make electronic instruments for particle physics experiments.

We have adequate computing support to do active software development and data analysis locally, in addition to the resources available elsewhere in the collaboration for running larger computing jobs. The neutrino group's computers are administered by faculty and staff members. Other general computing support is provided by the campus computer support. There is also a computer visualization laboratory on campus.

The neutrino group is active in several forms of scientific and educational outreach. Because the MINOS far detector is so close, we help with the yearly open-house and pre-scheduled school group tours. We play a role in an outreach program that sends high school teachers for an outreach experience at the mine. The local SPS chapter is involved doing physics demonstrations at local schools. Finally, several students obtain a physics minor as part of their Science education degree.

Fermilab

Fermi National Accelerator Laboratory
P.O.Box 500 • Batavia, Il.• 60510-0500
630-840-3211 FAX 630-840-2900

Director's Office

January 25, 2006

Professor Kevin McFarland
University of Rochester
Department of Physics & Astronomy
Bausch & Lomb Hall
P. O. Box 270171
600 Wilson Boulevard
Rochester, NY 14627-0171

Dear Kevin,

This letter is in support of your proposal for an MRI grant for MINERνA.

The MINERνA Experiment (FNAL E-938) obtained Stage I approval from Fermilab in April 2004. After a further review from the FNAL PAC in April 2005, the laboratory physics advisory committee wrote:

> *"The Committee heard a presentation from MINERνA. The progress in R&D and in costing of the project since the Committee last saw the proposal was impressive. The Committee remains excited about the physics potential of the experiment. However, since the proposal received Stage I approval, the DOE has clarified its methodology for funding such projects. DOE Office of High Energy Physics funding for MINERνA is now expected to come through the Laboratory… [T]he Committee believes that the physics case for MINERνA remains strong, both as 'engineering' for neutrino oscillation experiments and as basic research in neutrino scattering. The Committee recommends that the Laboratory and the collaboration work towards the timely construction and operation of MINERνA."*

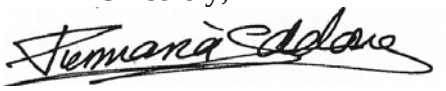
Since this time, Fermilab has funded significant detector R&D and design work towards the construction of MINERνA in both DOE FY05 and 06. The laboratory has established a project management team with both Fermilab and University representation, and with input from the Fermilab Office of Project Management Oversight. The DOE is currently awaiting CD-0 approval for MINERνA, and is preparing CD-1 documentation. MINERνA recently underwent a successful CD-1/2 review and is in the middle of preparing a baseline schedule, budget and technical design report. Fermilab has applied for an MIE to fund construction of MINERνA beginning in FY07.

The MINERνA MRI proposal seeks to consolidate and expand the capabilities of MINERνA by funding calibration systems and nuclear targets to study A-dependence in neutrino interactions. In particular, this proposal provides funds to construct a test beam detector to be operated in the Fermilab meson area test facility. Fermilab currently intends to maintain this

facility through the MINERνA construction period for use for detector development in neutrino experiments such a MINERνA and NOνA and for ILC detector development, and is developing plans to improve the facility's yield for low energy hadrons. This proposal also seeks to add a cryogenic helium target outside the scope of the original MINERνA proposal. If this proposal were funded Fermilab has agreed to provide necessary support infrastructure for this target, including engineering support, safety oversight and electrical and refrigeration infrastructure. Although a preliminary review of the proposed target shows no insurmountable hazards, installation of the proposed target will require a final safety assessment to be provided as part of the laboratory's contribution to the target.

I look forward to the MINERνA experiment and to the participation of the National Science Foundation in the experiment and in the enhanced capabilities promised by these items to be funded in this proposal.

Sincerely,



Piermaria Oddone,
Director

Organization Classifications

Research Proposal: Collaborative Proposal for Development of Nuclear Targets and Calibration Systems for the MINERvA Neutrino Experiment

University of Rochester: Ph.D. granting organization*

Subcontractors:

Hampton University: Non-Ph.D. granting organization**

University of Minnesota, Duluth: Non-Ph.D. granting organization

University of Pittsburgh: Ph.D. granting organization

College of William and Mary: Ph.D. granting organization

*See attached letter from University of Rochester

**A letter from Hampton University is attached to clarify its non-Ph.D. granting status

UNIVERSITY OF
ROCHESTER

OFFICE OF RESEARCH & PROJECT ADMINISTRATION

January 26, 2006

National Science Foundation
4201 Wilson Blvd.
Arlington, VA 22230

Re: Major Research Instrumentation Program

To Whom It May Concern:

As required by the MRI program guidelines, this letter is to confirm that the University of Rochester is a Ph.D. granting institution.

Should you need any further information, please do not hesitate to contact our office.

Sincerely,

Gunta J. Liders
Associate Vice President for
Research Administration

5th Floor, Hylan Building
University of Rochester
P.O. Box 270140
Rochester, New York 14627-0140
(585) 275-4031
Fax: (585) 275-9492

Certification of RUI Eligibility

"By submission of this proposal, the institution hereby certifies that the originating and managing institution is an institution that offers courses leading to a bachelor's or master's degree, but has awarded an average of no more than 10 doctoral degrees per year in NSF-supported disciplines over the 2-to-5 year period preceding proposal submission."

Authorized Institutional Representative:

Hampton University
Doretha J. Spells, Vice President for Business Affairs and Treasurer
Typed Name and Title

Signature: _____ **Date:** 1/19/05